COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

ENGINEERING
LIBRARY

June, 1948

JUL 9 1948

Oneida Street, the first central station to burn pulverized coal—see page 32

Developments in Burning Pulverized Coal ▶

CORROSION: Its Effect in Boiler Systems—Part II ▶

Feedwater and Blowoff Calculations ▶

Recent C-E Steam Generating Units for Utilities

GRAND AVENUE STATION

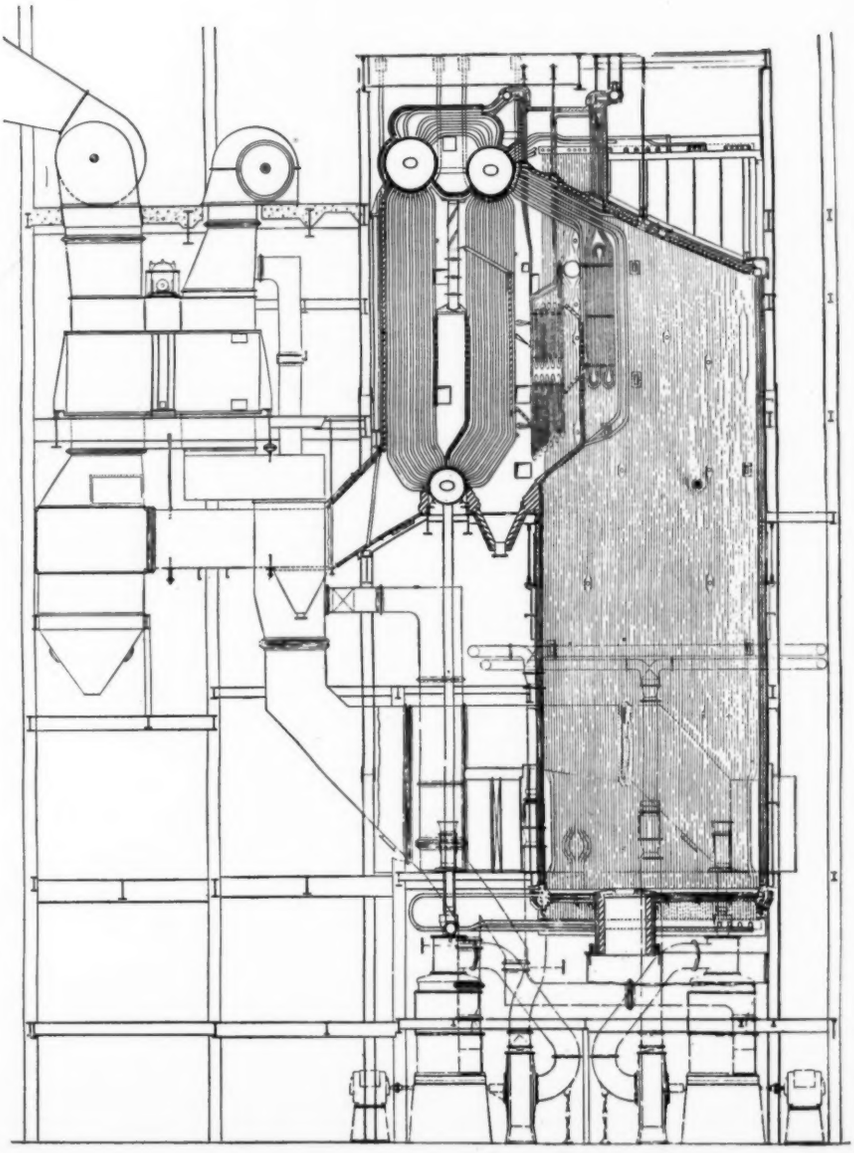
KANSAS CITY POWER & LIGHT COMPANY

THE C-E Unit illustrated here is now under construction at the Grand Avenue Station of the Kansas City Power & Light Company, Kansas City, Missouri. When completed, this will be the seventh C-E Steam Generating Unit in this station.

This latest unit is designed to produce, at maximum continuous capacity, 375,000 lb steam per hr at 650 psi and a total temperature of 950 F.

It is of the 3-drum type with 2-stage superheater. The furnace is fully water cooled, using closely spaced plain tubes on all walls and finned tubes in the roof area; it is of the continuous slagging bottom type. A regenerative type air heater follows the boiler surface.

Pulverized coal firing is employed, using C-E Raymond Bowl Mills and C-E Tangential Burners. B215



COMBUSTION ENGINEERING

200 MADISON AVENUE · NEW YORK 16, N. Y.

C-E PRODUCTS INCLUDE ALL TYPES OF BOILERS, FURNACES, PULVERIZED FUEL SYSTEMS AND STOKERS; ALSO SUPERHEATERS, ECONOMIZERS AND AIR HEATERS

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME NINETEEN NUMBER TWELVE

CONTENTS

FOR JUNE 1948

FEATURE ARTICLES

Developments in Burning Pulverized Coal—

Pioneer Work at Milwaukee ..... *by F. L. Dornbrook* 32

Lessons from the Tests and Present Status of the Art ..... Part I *by B. J. Cross* 36; Part II *by E. M. Powell* 39

Fuels Performance at Port Washington Station ..... *by W. A. Pollock* 41

Corrosion: Its Effect in Boiler Systems—Part II ..... *by Robert L. Reed* 43

Feedwater and Blowoff Calculations ..... *by V. J. Calise* 51

EDITORIALS

Financing Utility Expansion 31

Smoke in New York 31

DEPARTMENTS

Review of New Books 55

General and Classified Index, Vol. 19, July 1947 through June 1948 59

Advertisers in This Issue 64

GERALD S. CARRICK, *General Representative*

ALFRED D. BLAKE, *Editor*

THOMAS E. HANLEY, *Circulation Manager*

Published monthly by COMBUSTION PUBLISHING COMPANY, INC., 200 Madison Ave., New York 16
A SUBSIDIARY OF COMBUSTION ENGINEERING COMPANY, INC.

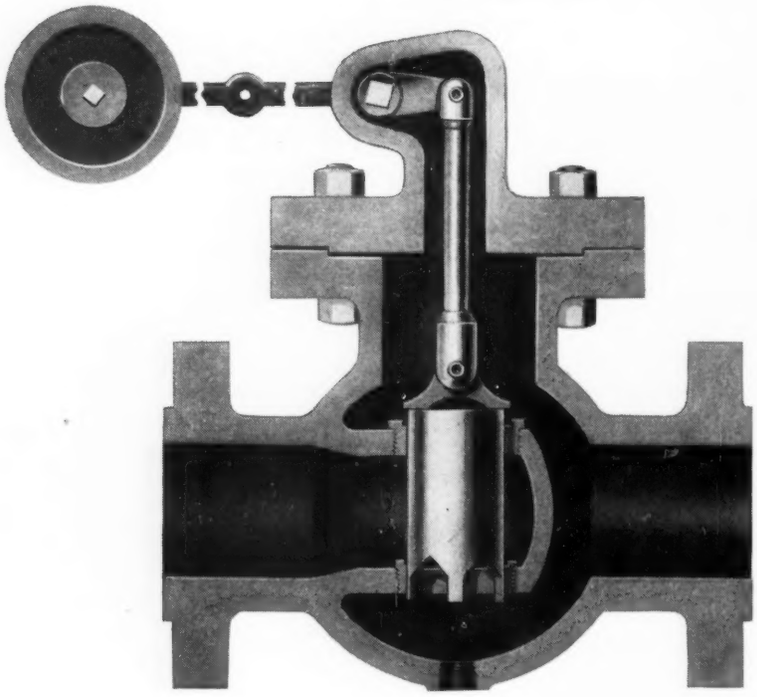
Frederic A. Schaff, President; Charles McDonough, Vice-President; H. H. Berry, Secretary and Treasurer.

COMBUSTION is sent gratis to engineers in the U. S. A. in charge of steam plants from 500 rated boiler horsepower up and to consulting engineers in this field. To others the subscription rate, including postage, is $3 in the United States, $3.50 in Canada and Latin America and $4 in other countries. Single copies: 30 cents.
Copyright 1948 by Combustion Publishing Company, Inc.
Issued the middle of the month of publication.

Publication office, 200 Madison Ave., New York CCA Member of the Controlled Circulation Audit, Inc.

Printed in U. S. A.

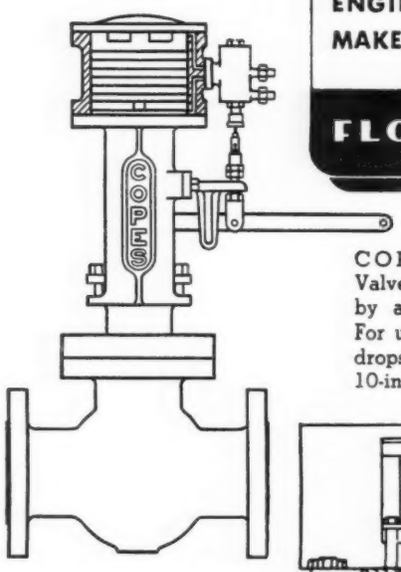
COPES BALANCED VALVES



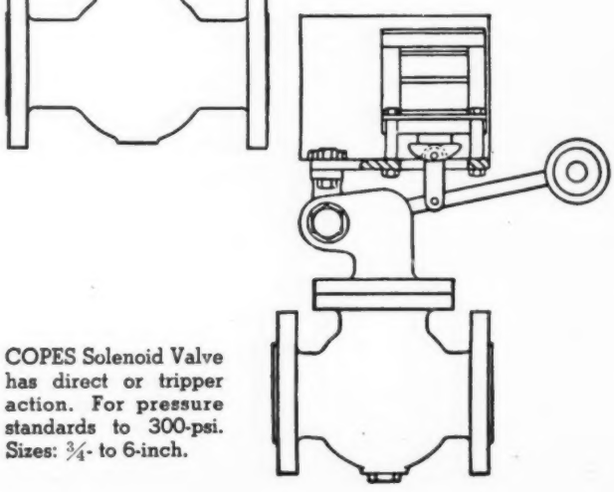
A valve may be statically balanced while at rest, yet be so badly unbalanced dynamically—when handling flows under pressure—that inaccurate response to the actuating element causes a "hunting" action which makes impossible the desired precision of control. In COPES Valves, unbalanced forces are held within narrow limits over the entire operating range. This is why so many have been purchased *at a premium,* where control must be precise with actuation by float, solenoid or other element. Sizes: ¾-inch and up. When writing for data, give complete information on your operating needs.

ENGINEERED BY THE MAKERS OF **COPES**

FLOWMATIC



COPES Type SLH Valve, relay operated by air, oil or water. For unlimited pressure drops. Sizes: 1½- to 10-inch.



COPES Solenoid Valve has direct or tripper action. For pressure standards to 300-psi. Sizes: ¾- to 6-inch.

NORTHERN EQUIPMENT COMPANY

686 GROVE DRIVE, ERIE, PA.

BRANCH PLANTS: Canada, England, France and Austria

Representatives Everywhere

COPES

Headquarters for . . .

Boiler Feed Water Control . . . Excess or Constant Pressure Control, Steam or Water . . . Liquid Level Control . . . Balanced Valves . . . Desuperheaters . . . Boiler Steam Temperature Control . . . Hi-Low Water Alarms.

EDITORIAL

Financing Utility Expansion

Several speakers at the recent Edison Electric Institute Convention in Atlantic City deplored the present shortage of new investments in electric utility stocks to finance that industry's vast expansion program which is so necessary to meet the ever-growing load demands. This program, it is estimated, will cost in the neighborhood of six billion dollars over the next five years, close to two-thirds of which will have to be raised through the sale of securities to the investing public.

The dearth of such potential capital was attributed to present high individual surtaxes and to the relatively low net earnings of many utilities as a result of high taxes and mounting fuel, material and labor costs, with rates that are largely static.

Heretofore, increased volume of sales, together with improved efficiencies and other operating economies, have been depended upon to offset higher operating costs; and many leaders in the industry have been accustomed to point with pride to the fact that such means have enabled existing rates to be maintained, or in some cases reduced, during a decade of constantly mounting costs.

That this now ceases to suffice is attested by a recently issued report of the Federal Power Commission showing that, although gross operating revenues of the large privately owned electric utilities for the first quarter of this year were 12.9 per cent above those for the corresponding period of 1947, operating expenses had increased 17.5 per cent. Thus the average net income showed a decrease of some $2^1/_2$ per cent.

Since adequate power capacity and facilities are vitally essential to both our economic welfare and national defense, steps must be taken to assure adequate investment for this purpose. If it means applying to the regulatory bodies for some increase in rates, as many of the speakers at Atlantic City believed necessary, the situation must be faced notwithstanding political issue that may be raised.

Electric utility securities under present safeguards, with assured load demands providing a unique stability, and with a fair rate of return, should be most attractive to the conservative investor.

Smoke in New York

Early this month the Smoke Prevention Association of America held its Forty-first Annual Meeting in New York City. Selection of this city as the place of meeting was timely inasmuch as New Yorkers have been showing revived interest in atmospheric pollution, and the publicity accorded the various talks and papers in the local press should be helpful in stimulating civic interest in the matter.

Health Commissioner Harry S. Mustard, whose department is charged with enforcement of the smoke ordinance and with corrective measures, spoke of the steady, increased use of bituminous coal and oil to replace anthracite over the past fifteen years, and announced the plans which had been made to cope with the problem. These included a tightening of the inspection service, an educational program and research.

It will be recalled that during the middle thirties an exhaustive investigation of atmospheric pollution in New York was made with PWA funds and personnel. This report should still be of much assistance as a basis for the work now being undertaken and its use will avoid duplication of effort.

However, as is now well understood, it is not smoke alone that is usually responsible for bad atmospheric conditions; topography, prevailing winds and certain other local conditions also exert a controlling influence. Studies by Hebley, Neuberger and others have confirmed these facts and their reports are available. Furthermore, experiences in improving conditions in other American cities, notably Pittsburgh and St. Louis, where conditions were infinitely worse although not strictly comparable, should provide ample background for those charged with solving the problem in New York.

The Citizens Union is actively behind the movement and the American Society of Mechanical Engineers, through its Metropolitan Section, has been invited to co-operate and render technical assistance.

Although a new proposed city ordinance, providing stiff penalties for violations, has already been introduced in the City Council, it is to be hoped the problem will be approached in a constructive way.

DEVELOPMENTS IN BURNING PULVERIZED COAL

Just thirty years ago the first successful application of pulverized coal firing to power boilers was made at the old Oneida Street Plant of the Milwaukee Electric Railway & Light Company (since renamed the Wisconsin Electric Power Company). It was therefore fitting that the Semi-Annual Meeting of the A.S.M.E. in Milwaukee should devote a session on June 4 to this pioneer work and some of the later developments emanating from it. Two of the authors, F. L. Dornbrook and B. J. Cross, were associated with the initial installation, the former in connection with its design and operation and the latter with the testing. Mr. Powell deals with later developments in pulverized coal firing and Mr. Pollock with performance at the Port Washington Station which embodied lessons from experience gained in the earlier installation. Excerpts from these several papers follow.

Pioneer Work at Milwaukee

By F. L. DORNBROOK*

AT THE time of the first world war, in 1917, coal was burned in the Milwaukee power plants on underfeed stokers, and boiler units were of the order of 468 to 810 bhp. Efficiencies were those usual for that day, outages were frequent and accepted, and the quality of coal was becoming poorer while its cost was increasing. It had been burned in pulverized form for about 25 years in the manufacture of cement; it had been employed in annealing and forging furnaces, as well as in the manufacture of refractories, and some work had been done toward application to locomotives; but no one had appreciated the economies and advantages of applying pulverized coal to stationary power boilers.

Oneida Street Power Plant

When faced with higher coal costs and stoker selection to burn every kind of available coal, it was thought that better results could be obtained if the coal were burned in pulverized form. That was the birth of a trial installation in the Oneida Street power plant in Milwaukee early in 1918, on one boiler and shortly thereafter on four more boilers. New stokers which were on order for five 468-bhp, 160-psi boilers were redesigned and transferred to other boilers and the five boilers were equipped with furnaces and burners for firing pulverized coal. The management felt it desirable to have a supply of pulverized coal in storage above the boilers rather than to burn the coal as it was milled. Such problems as drying and conveying the coal, condensation of moisture in bins and furnace slagging, had not yet become nightmares to disturb the dreams of the bold pioneers.

By November 1919, it was possible to perform tests on the five boilers, with a mixture of pulverized screenings. A test of 99 hr duration, or a total of 495 boiler hours, showed a gross efficiency of 80.67 per cent. Paul Thompson of The Detroit Edison Company was present throughout the test as an observer. A test of a stoker-fired boiler in the same plant showed a gross efficiency of 75.8 per cent. The comparative efficiencies after accounting for coal preparation and incidental charges, were reported as 72.32 per cent and 70.88 per cent or a difference in favor of the pulverized fuel system of 1.44 per cent. The results were reported in a paper prepared by the late John Anderson.

In 1923 the U.S. Bureau of Mines published[1] the results of a series of 38 tests made between June and December 1920. These tests were conducted by Messrs. Henry Kreisinger, John Blizard, C. E. Augustine and B. J. Cross. The investigations were thorough and covered many phases of the subject, including:

(*a*) Coal fineness.
(*b*) Coal moisture.
(*c*) Excess air variations.
(*d*) Performances with round and spreading burners.
(*e*) Products of combustion.
(*f*) Furnace temperatures.
(*g*) Heat absorption coils in furnace.
(*h*) Efficiencies of 64 to 84 per cent.

They showed that a coal fineness of 80–85 per cent through 200 mesh was unnecessary and that fineness of 60–65 per cent through 200 mesh for the coal being used was practically efficient. This permitted higher ca-

* Chief Engineer of Power Plants, Wisconsin Electric Power Company.

[1] "An Investigation of Powdered Coal as Fuel for Power Plant Boilers," by H. Kreisinger, John Blizard, C. E. Augustine and B. J. Cross, U. S. Bureau of Mines, Bulletin 223, 1923.

pacities of the mills and lower costs of preparation. The tests also showed that moisture reduction to 1 per cent was not necessary for efficiency and that even undried coal could be burned efficiently. However, undried coal was found to give troubles in conveyors and in storage bins and affected mill capacity. It was further demonstrated that proper burner design, furnace design and air admission were important factors in the process.

The tests, as well as the operating experience up to this time, revealed the advantages now obvious for burning pulverized coal; namely, wide fluctuations of load are possible in brief periods of time, and the quick response of furnace conditions gives the process a big advantage over other methods of firing. Maintenance of high CO_2, low CO and reduction of combustible losses permit high efficiencies to be attained. Also banking losses can be reduced to a minimum, variable coal qualities can be accepted; and absence of moving metal parts in the furnace makes for a maintenance advantage and reliability.

The need to reduce the costs of coal preparation, power requirements and equipment maintenance, was a constant urge. Continuous and uniform operation of dryer and pulverizer equipment with varying quality of coal presented never-ending problems.

Lakeside Power Plant

In 1916, before the war, the Milwaukee company had been making plans for a new power generating station on the lake shore, south of the city. It was intended to install two 20,000 kw turbine-generators and eight 1306-bhp boilers to operate at 300 psi, with stokers. The project had to be deferred because of the war and when it was resumed in 1919, a decision was made to fire the eight boilers with pulverized coal. This was a bold departure from the accepted practice of the day, and it was taken despite considerable differences of opinion and doubt among leading engineers. For Lakeside, the storage system, sometimes called bin-and-feeder system, was adopted on the basis of the experimental installation at Oneida Street.

At Lakeside it was considered desirable to prepare the coal in a building separate from the boiler house. This building, called the pulverizer house, had a raw coal bunker of 3500 tons' capacity. Coal was delivered to the bunker by 36-in. belt conveyors after being dumped from railway cars by a rotary car dumper, passed over a magnetic pulley to remove tramp iron, and then crushed by hammer mills to $^1/_2$ in. size. Coal from the bunker was conveyed by 16-in. screw conveyors to three rotary drum-type coal dryers like those used in cement manufacture and fired by pulverized coal. These three dryers each had an approximate capacity of 25 tons per hour, reducing moisture from 5 to 2 per cent. The dried coal was handled by bucket elevators and distributed by screw conveyors to eight 7-ton-per-hour Fuller ball-type mills. The pulverized coal, separated by cyclone collectors, was deposited in bins by fuel pumps and was conveyed through 5-in. pipes by compressed air to the storage bins above the boilers.

Each of the eight boilers had three duplex screw feeders and six burners of the Lopulco fan-tail type which fired down through an arch of the front wall of the furnace. The original furnace was built of solid refractory and had no water cooling surfaces at the bottom or sides.

Firing aisle at Oneida Street Station

In 1925 the Bureau of Mines published[2] the results of a series of 26 tests made during the period from May to October, 1921. These tests were made by the same four engineers who had conducted the 38 tests at Oneida Street one year previously, namely Messrs. Henry Kreisinger, John Blizard, C. E. Augustine and B. J. Cross. As usual, these men were thorough and their tests covered many phases of the subject. Efficiencies of boiler, superheater and economizer were reported, ranging from 84 to 91 per cent.

There is no question in the writer's mind that the wide acceptance of pulverized coal on the part of the industry was due in a large measure to the painstaking care and thoroughness with which these test engineers performed and reported their findings under the direction of the U. S. Bureau of Mines.

Early Problems

At this point, it is interesting to recall some of the early obstacles that had to be overcome:

HANDLING RAW COAL. Conveying the raw coal was a major problem due to seasonal variations of moisture and variations of fineness. Belt conveyors gave little trouble because they had been designed with ample margin in capacity, which usually is the best way to avoid trouble. On the other hand, screw conveyors gave much trouble, such as breakage of the screw flights due to clogging with wet and fine coal, breakage of weak bearing supports, under motoring due to lack of accurate data for calculations, wear of the troughs, wear in chutes, corrosion in coal valves and difficulty in getting an even feed of coal from bunkers into the conveyors. It became necessary to design and build special star feeders to get the coal out of bunkers.

Coal scales which had been provided to weigh the coal into the rotary dryers gave difficulties which were solved only by the decision that the information these scales gave did not warrant the work necessary to keep them trouble-free, so they were eliminated entirely.

PREPARING AND STORING PULVERIZED COAL. Fires in rotary dryers due to variations in moisture were frequent. Excessive dusting of the vents became a nuisance. Wear in the bearings and internal parts of these large rotating drums added to the work of the maintenance mechanics. Wear in the pulverizers was a continual problem. The balls would wear out of round and replacement was necessary. Coal transport piping would clog and required blowout connections. Wear in pipe bends required use of extra-heavy pipe walls and seamless steel pipe was adopted to reduce the hazard of splitting of lap-welded pipe. Pulverized coal in storage bins suffered from condensation of moisture caused by cold drafts of air on the side of the bins. However, insulation overcame the sweating to a large extent. The moisture also caused corrosion of the steel in the storage bin, which was lessened by the use of insulation and the use of double wall bins. It was also discovered to be poor practice to make use of the structural steel building beams as a part of a coal storage bin, or to run a beam through the inside of a coal storage bin, because this steel would be subjected to corrosion. Sufficient steepness of the valley angles of a bin was found to be a major consideration in the design of a coal storage bin that would empty itself.

BURNING PULVERIZED COAL. Feeder screws would wear and cause variations in coal feed and flooding of coal to the burners. New screws with various types of threads and of different materials were tried, and on later installations the displacement type of feeder superseded the screw feeder. The original variable-speed belt drives required much mechanical adjustment, and on later installations, variable-speed direct-current motor drives were used. Under-motoring of feeders was an initial difficulty.

Burning off of burner tips was reduced by changes in dimensions, and by use of air admitted around the burner. Clogging of burners was reduced by changes in dimensions and means to rod out. Furnace designs were changed repeatedly to obtain the volume needed for burning pulverized coal and to add heat-absorbing surface in the furnaces to overcome slagging. The author outlined the development of furnace design for pulverized coal firing in a paper presented to the Society in June 1940[3].

In general, as each problem was faced and a solution found, the system became essentially trouble-free and more reliable. Many troubles were avoided by adhering to the following guiding policies:

1. Eliminating a piece of faulty apparatus by substituting a new design, or if possible, a new method, such as elimination of screw feeders mentioned above.
2. Providing a greater "margin of safety" when replacing a broken part.
3. Allowing more space in the layout to facilitate maintenance and providing permanent trolleys and hoists to handle replacement parts.
4. Providing more margin in capacity of motors and gears.
5. Placing the exhauster fan on the outlet of the collector and providing heavier fan blades.
6. Acquiring more skill and experience in operation and encouraging suggestions for improvements from the operators. Providing the operating engineers with printed instruction books to explain the equipment they operate.

Lakeside Boiler Room No. 2

In 1923 the company added eight 300-psi boilers of 1828 bhp each, to serve three additional turbine-generators of 30,000 kw each. These new boilers had larger furnaces and were provided with screen tubes at the bottom of the furnace, connected into the boiler circulation system. Radiant superheaters were added on the rear wall. The refractory settings were built with air cooling ducts and all the refinements developed during the preceding years were incorporated.

The original milling capacity was not sufficient to serve the old and new boilers; hence two 15-ton per hour Raymond roller mills of the latest design were installed in the pulverizer house. Coal drying preceding the milling had been a constant problem and it was decided to add gas dryers and later steam dryers of a vertical type instead of horizontal rotary dryers. These new dryers were not successful, because they had too low a capacity with wet coal, dusted excessively and wore to such an extent that leaking of steam often offset the drying that was desired. It was not until the advent of drying coal in the mill, using hot waste flue gas, that the major problems of drying coal and maintaining full mill capacities were

[2] "Tests of a Large Boiler Fired with Powdered Coal," by H. Kreisinger, John Blizard, C. E. Augustine and B. J. Cross, U. S. Bureau of Mines, Bulletin 237, 1925.

[3] "Development of a Major Principle in Pulverized Coal Firing," by Fred L. Dornbrook, A.S.M.E. Power Division, Semi-Annual Meeting, Milwaukee, Wis., June 17-20, 1940.

solved. Drying the coal in the mill with waste gas improves the overall boiler efficiency about 0.5 per cent. Elimination of the coal dryers and conveyors permitted reductions in investment costs. Drying coal in the mill was the subject of a paper[4] by the late M. E. Fitze, presented in 1940. However, there still remains a problem of controlling some coal dust escaping with the moisture-laden vented gas.

Lakeside Boiler Room No. 3

In the period from 1926 to 1930 the Company installed at Lakeside four 300,000-lb per hr, 1200-psi boilers with radiant superheaters and reheaters. The mills were placed adjacent to the boilers in the boiler room, for convenience. Again all the refinements of the previous years were incorporated.

East Wells Street Direct Firing of Pulverized Coal

The Company has one installation of a direct-fired boiler and therefore is not without some experience in burning pulverized coal directly. This installation consists of a 1000-bhp, 200-psi boiler for central steam heating in the previously named Oneida Street plant. This boiler has a furnace of 6800 cu ft volume, water walls, air heater, but no superheater. It is fired by two impact mills and has two round burners in the front wall for horizontal flame. It has been operating successfully since 1926, and is now practically trouble-free, although its safe range of load is limited.

[4] "Mill Drying of Coal," by M. E. Fitze, presented at meeting, Fuels Division, A.S.M.E., Birmingham, Ala., November 7–9, 1940.

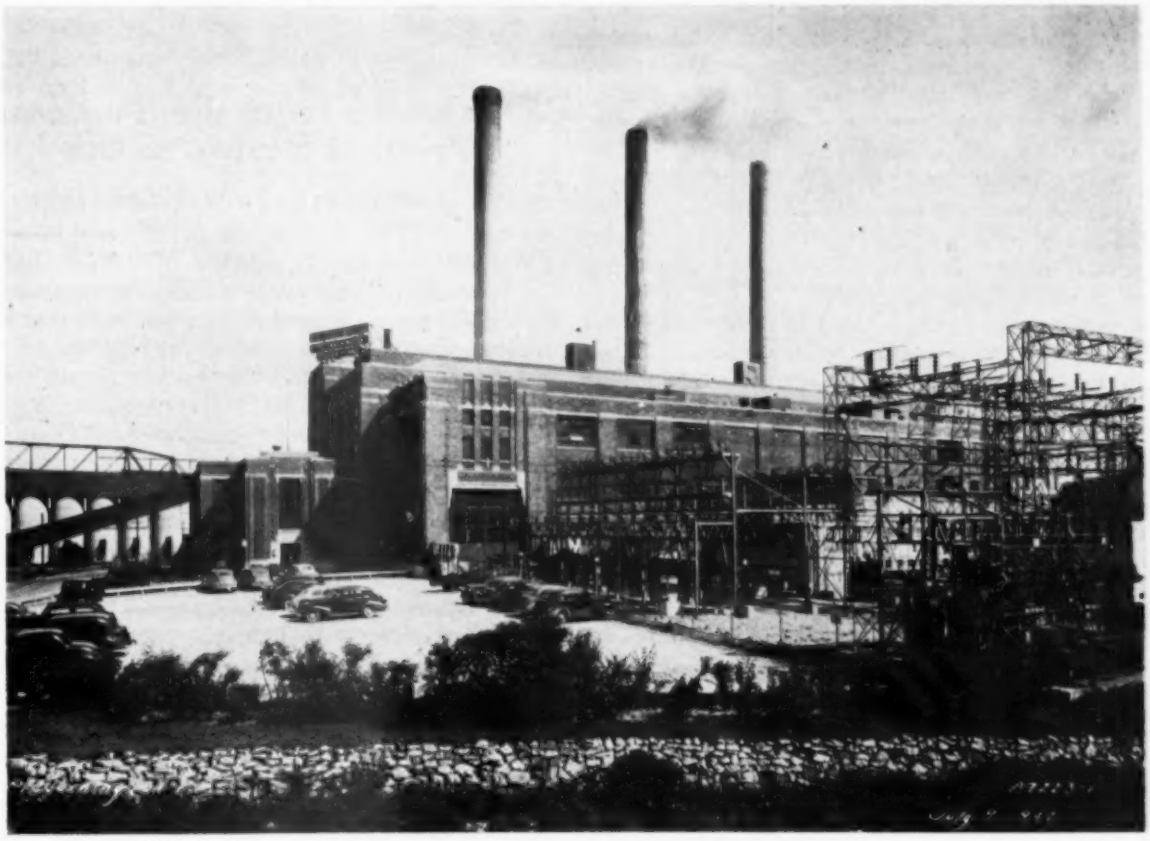
Port Washington Station

In 1930 the Company began the design of a new power plant at Port Washington, Wis., 26 miles north of Milwaukee on the lake shore. The first unit of 80,000 kw capacity was completed and went into operation in November 1935. The unit is a single-boiler, single-turbine design in which the boiler is rated at 690,000 lb per hr capacity, 1390 psi and has radiant superheaters on the side walls of furnace, radiant reheaters on the rear wall and finned tubes on the front wall and under the arch. Duplex displacement feeders, ten in number, feed the coal to the twenty burners which fire vertically through the arch of the front wall. Variable speed direct-current motors control the rate of feed automatically, and the fuel and air are regulated by steam flow–air flow which permits partial or complete automatic control or manual control. Coal is milled in two 15-ton per hour Raymond roller mills and is transported by compressed air fuel pumps to the bin above the boiler.

A second 80,000 kw unit began operation in 1943, a third 80,000-kw unit will be placed into operation in 1948 and a fourth of the same capacity unit is on order.

Some examples of the mill system refinements incorporated in the Port Washington installations are:

1. Improved lubrication of mill parts and mill auxiliaries.
2. Wearing parts easier to replace and redesign of internal parts to reduce wear.
3. Use of press fits for gears and cranks on their shafts.
4. Interchangeability of spare parts and spare motors.
5. Use of butterfly valves instead of gate valves where possible; improved shutoff gates; greater tightness of puff doors and inspection doors; and stronger flanges in ductwork joints to insure tightness.



Port Washington electric generating station

6. Thicker metal in ductwork where corrosion was experienced.
7. Guniting inside of cyclone collectors and fuel bins with concrete over mesh-wire cloth.
8. Interlocking mills and auxiliaries to insure correct starting sequence and complete trip-out in case of failure of any auxiliary, interlocking also, the lubricating oil pump for the mill,and interlocking the air supply to the fuel pumps.
9. Improved design of raw coal bunker with steep sides that can empty itself completely and enlarged connections between bunker and mills and elimination of ledges which would impede flow of coal.
10. Added indicating and recording instruments to assist the operators.

In developing refinements, formal tests were made following each redesign of a part. Tests were made on grinding rings, number of rollers to get best results, air ports, baffles, plow tips, cyclone collectors, exhauster fans and venting in a never-ending struggle for improvement to increase capacity, to reduce power requirements, to reduce maintenance costs and to improve reliability.

The equipment manufacturers have always been very cooperative in a joint effort to improve the apparatus and a large measure of credit should be given for their contribution to the successful developments of burning pulverized coal.

Some Features of Design

One feature of Milwaukee's designs for burning pulverized coal that should be mentioned is the use of dual forced-draft fans, dual induced-draft fans and dual primary-air fans. Double fans permit a flexible range in loading, greater reliability, and ability to continue to operate at about 60 per cent capacity with a single fan in case the other fan or its drive is out of service for repair. The use of dual auxiliaries has permitted long periods of continuous operation of the units.

Another feature of Milwaukee's method of burning pulverized coal is the use of large water and steam-cooled furnaces to avoid the formation of slag in so far as possible. It is realized that the larger furnace costs more and requires a larger building, but the Company's engineers firmly believe that the additional cost is warranted by freedom from slagging troubles. The maximum rate of heat release is in the neighborhood of 15,000 Btu per cu ft. Use of maximum cooling surfaces, water and steam, and minimum of refractory is responsible for the low temperature and freedom from slag troubles.

To remove furnace bottom ash from pulverized coal furnaces, the sluicing-type ash conveyors were found satisfactory and are used wherever the site and conditions permit. The ideal system is one in which the ash can be sluiced in a trough to an outside dewatering pit without the need of clinker grinders or pumps to handle the ash. Pumping the water from the settling pit, minus the ash, is not a difficult problem. Previous designs required removal of ash from furnace bottoms with manual and mechanical hoes, but the present sluicing of the bottom of furnaces eliminates personnel accidents and avoids the kind of fatiguing work that discourages the employment of men who could be trained to higher positions in the plant. Sloped troughs are built in the furnace bottom and ash is removed by water jets. The layer of ash keeps the bottom of the furnace relatively cool and the refractories have been surprisingly free from trouble due to contact with water.

When burning pulverized coal, more soot blowers will be required with the steady deterioration of quality of coal and shortage of labor. Various types of retracting soot blowers have been tried and installed to eliminate hand lancing at hot locations and the latest installation will have the air-puff blowers in the boiler passes with remote control of automatic sequence blowing.

Advantages of Bin-And-Feeder System

Advantages of this method are as follows:

1. Coal is stored in the bins during the off-peak periods to be burned during the peak load hours. Such a system requires fewer mills and can use mills of the most economical size for pulverizing, because the size and design of mills are not prescribed by the variable requirements of the boiler.
2. The bin-and-feeder system permits the mills to operate at constant load and under conditions most favorable for high mill output, for controlled quality of pulverization and for low milling costs. The boiler, on the other hand, can be fired without reference to control of the mills. The functions of each can be controlled independently of each other and to the advantage of each.
3. At Port Washington the pulverized fuel transport system permits coal to be furnished to any boiler from any mill. Hot gas and vent ducts are also arranged so that mills can operate without the adjacent boiler being in service.
4. The bin-and-feeder system permits control of the flame and flame position necessary with use of radiant superheaters and radiant reheaters in the control of steam temperature.

The Company employs the radiant superheater and the convection superheater piped in series, to give a flat temperature characteristic throughout a wide range of boiler capacity. It also employs a radiant reheater in combination with the variable exhaust temperature from the high-pressure turbine to produce a flat temperature characteristic of reheated steam throughout the range of load. Use of the bin-and-feeder system with radiant steam heating surfaces gives a control of steam temperature not possible with some other types of firing.

5. Explosion in mills and fuel storage bins has been nonexistent since the use of waste flue gas in the mill for drying and for ventilation of the storage bin.

No claim is made that the method developed in Milwaukee for burning pulverized coal is the only one to use, but it has been successful and efficient as there applied.

Lessons from the Tests and Present Status of the Art

Part One—by B. J. CROSS*

SHORTLY after the Oneida Street installation was completed it was subjected to a critical study and a series of complete tests by the Fuel Section of the U. S. Bureau of Mines in cooperation with the Wisconsin Electric Power Company and Combustion Engineering Company. During this series of tests progressive changes were made as dictated by the information obtained. The technical data and experience gained pointed the direction along which future development was to progress.

Like all settings of that day, the furnace walls of the Oneida Street boilers were entirely of refractory. Exposure of boiler surface to the radiant heat of the furnace was only incidental to the necessity of locating the boiler over the furnace. In fact, the belief was then widely held that exposure of water-cooled surface in the furnace was detrimental to good combustion.

Early in the series of tests it became evident that this refractory furnace imposed severe limitations on the rate of combustion and on the reduction of excess air; and that it would not be possible to realize fully all of the advantages inherent in the firing of boilers with pulverized

* Manager, Research Dept., Combustion Engineering Company.

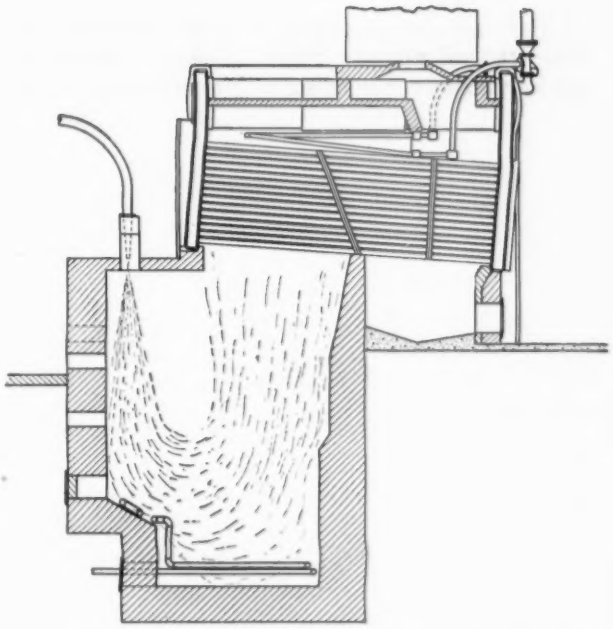


Fig. 1—Section through Oneida Street boiler

coal unless more heat-absorbing surface could be provided in the furnace. The improvised water coil shown in Fig. 1 was one of several tried in the attempt to reduce or remove the limitations of the refractory furnace.

From the results of tests made with this limited extent of water-cooled surface in the furnace, it was possible to prepare and to appreciate the significance of the curves shown in Fig. 2.

Earlier attempts to burn pulverized coal under boilers had failed because the furnaces were too small. It was found that there was a definite limit in the amount of coal that could be burned in a furnace of a given size, and the unit of furnace performance became the "Btu per cubic foot per hour."

With radiant heat-absorbing surface in the furnace, the more logical unit is the "Btu per hour per square foot of heat-absorbing surface." As experience established the heat-transfer rates, it became possible to predict and to design for specific furnace gas outlet temperatures.

The abscissa of the curves shown in Fig. 2 represents the heat liberated per square foot of projected radiant heat-absorbing surface. The ordinate represents the heat absorbed per square foot, or as it is shown, the furnace temperature.

The projected area of water-cooled surface exposed to the furnace was approximately 100 sq ft. With the fusion temperature of the ash limiting furnace temperature to 2200 F, it may be seen that the limitation in the permissible heat liberation rate at 20 per cent excess air is 165,000 Btu per sq ft of surface, or a total of 1375 lb of coal per hour. If a higher rate of burning were desired or required, the excess air would have to be increased at a sacrifice of efficiency.

In the few years following the Oneida Street tests, installations of pulverized-coal-fired boilers were made in various parts of the country, each with successively more water-cooled furnace surface. The increase in cooling surface was made cautiously because of the apprehension over the effect on combustion. This fear, however, was soon dispelled and in 1924 in a paper before the A.S.M.E. Henry Kreisinger made the following statement: "Powdered coal can never be a complete success until the boiler is built around the furnace."[1] Furnace development then rapidly proceeded to that end and within three years of that date the first completely water-cooled furnace was in successful operation. In many present-day designs the boiler has entirely disappeared and all of the steam generated is made in the furnace walls.

Although the actual burning of the fuel takes place only in the furnace, the other components of a pulverized fuel system, such as the dryers, pulverizers, feeders and burners must all be considered as parts of the combustion system. Any deficiency in their performance will adversely affect the process of combustion in the furnace.

Coal Preparation, Drying and Pulverizing

In the early period of pulverized coal development strict requirements existed for coal moisture and fineness. The generally accepted formula was "less than 1 per cent moisture and at least 85 per cent through 200-mesh screen." Pre-drying of the coal before pulverizing was considered a necessity and the usual preparation plant which by regulation had to be in a separate building, became an imposing structure. Rotary driers were standard and the fuel and power costs were high, particularly for the high-moisture mid-western coals. Other types of dryers using gas or steam as a source of heat were investigated but none proved very satisfactory.

Drying coals during pulverization with the elimination of the separate dryer has proved to be the answer, and this method is now standard practice. Either hot flue gas or preheated air is used. In storage systems, the

[1] "A Review of Recent Applications of Powdered Coal to Steam Boilers," by Henry Kreisinger, presented at the Annual Meeting of the American Society of Mechanical Engineers, New York, December 1 to 4, 1924.

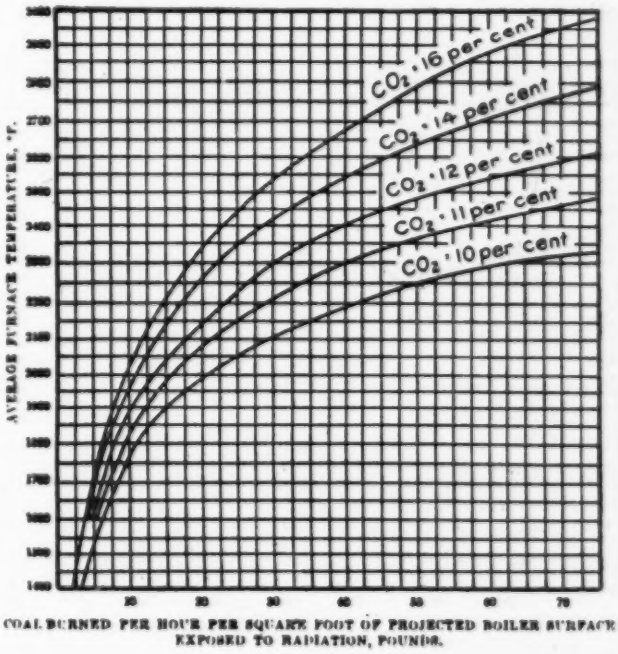

CO_2 - 16 per cent
CO_2 - 14 per cent
CO_2 - 12 per cent
CO_2 - 11 per cent
CO_2 - 10 per cent
AVERAGE FURNACE TEMPERATURE, °F.
COAL BURNED PER HOUR PER SQUARE FOOT OF PROJECTED BOILER SURFACE EXPOSED TO RADIATION, POUNDS.

Fig. 2—Average temperature of products of combustion plotted against different burning rates, for various values of CO_2 (reproduced from original report)

heated air or gas is added at the mill inlet and vented from the system after the cyclone separator. The moisture limit for the pulverized coal varies with the class of coal from 2 to 3 per cent for eastern bituminous coals to 25 to 30 per cent for sub-bituminous coals and lignites. The only limitation of moisture content of the raw coal is as it affects the handling and feeding of coal to the pulverizer.

In direct-firing systems heated air is the rule and all moisture removed from the fuel must necessarily be discharged into the furnace instead of being vented to the atmosphere as in the storage system.

MILLS. The coal pulverizers of today resemble those of 1918 just about as much as the modern automobile resembles the models of that earlier day. The mills are now all of the air-swept type and are adjustable for fineness of product. They are clean and quiet in operation. Power requirements have been reduced and availability greatly increased. They are made in capacity up to 25 tons per hour.

The mill feeders may be controlled automatically. For the storage system the feeders are regulated to give the maximum mill output. In direct-fired systems, the feeders must respond to the steam load demand.

The Oneida Street tests indicated that the fineness of coal could be considerably reduced without seriously affecting the efficiency. As more experience was gained it developed that the economic degree of pulverization varies with the class of coal and in general the lower the volatile, the higher is the required fineness. The range of fineness requirements as measured by per cent through the 200-mesh screen is from 65 per cent for lignites and sub-bituminous to 75 per cent for low-volatile eastern bituminous coals. As a general rule, the lower volatile coals are more easily pulverized and the higher fineness requirements may be met without sacrifice of mill capacity.

FEEDERS. Practically all the early pulverized fuel feeders were of the screw type, the inlet end being at the bottom of a bunker and discharging through a tubular member into the stream of carrier air. These feeders ran at relatively high speeds and wore out rapidly. Modern pulverized fuel feeders are of the rotary pocket type. They may be made in larger capacity and turn at much lower speeds. They are more positive and the discharge is directly proportional to the speed. Similar types of feeders are also used to supply the crushed coal to the pulverizer.

BURNERS. The burners serving the refractory furnaces were designed to produce "soft" flames and care was taken that there be no impingement on the brickwork. About 15 per cent of the air required for combustion served as carrier or primary air, the remaining air required for combustion being supplied progressively along the path of the flame. This air was supplied under natural draft and was admitted at low velocity so as not to produce excessive turbulence.

With the advent of the completely water-cooled furnace, the limitations imposed by refractories were removed and burners were designed for turbulence in order to promote a more rapid mixing of fuel and air and to give more rapid and more complete combustion.

Three different general types of burners are in use today namely, the vertical, horizontal and tangential types.

The vertical burner in principle is similar to those of the original Oneida Street boilers. All air is supplied under pressure, the primary air carrying the fuel from the feeder to the burner, secondary air through the front wall ports, and tertiary air around the burner. The air supplied through the vertical wall below the burner is in the form of high-velocity jets which impinge upon the streams from the burners. Adjustment of flame length and travel is possible by proportioning the pressure and quantity of the three air supplies. This burner originated in and has reached its highest development in plants of the Wisconsin Electric Power Company; hence it may very aptly be termed "the Milwaukee burner."

In the horizontal, or as it has been called, the horizontal turbulent burner, all of the air for combustion is introduced at the burner. The primary air is given a whirling motion within the burner so that it spreads as it emerges from the nozzle much as does the discharge from a water spray nozzle. The secondary air enters around the coal nozzle and is also given a spin in the same direction as the primary stream.

These burners may be made in larger individual capacity than the vertical burners and are best adapted to direct-fired installations where it may be undesirable to divide the discharge of a mill into a number of small streams. They are widely used in the furnaces of industrial boilers, as well as in some of the large central station units.

Tangential burners are set in groups of four disposed in substantially a horizontal plane located in the lower half of a furnace. They are directed toward a tangent circle at the center of the furnace and the interaction of the burners produces a spin within the furnace which promotes turbulence for mixing and resultant complete and rapid burning. Tangential burners may be made adjustable in the horizontal plane to control the distribution of coal in the furnace and adjustable in the vertical plane for the purpose of controlling the furnace outlet temperature.

The tangential method of firing is well adapted for furnaces of large plan section. By this means the fuel streams can be mixed and fully distributed over the furnace section so that the entire volume of the furnace may be fully utilized for the combustion process. All three types of burners may be used with either storage or direct-fired systems.

AIR HEATERS. In the days of refractory furnaces, the use of air heaters for preheating the air for combustion could scarcely even be considered. In many furnace designs, air at room temperature was passed through the hollow walls in order to keep the refractory lining at a safe temperature. With the development of water-cooled furnace walls, the use of the air preheater became possible and its application to steam generating units could proceed only as fast as the furnace walls were protected. Although the preheating of the air probably has little actual effect on the combustion process, it does add to the efficiency of the steam generating unit. Also, by reducing or even replacing economizer surface, it permits the wider use of stage bleeding of the turbine for reducing heat losses to the condenser.

When flue gas is used to heat the air for combustion, the heat capacity of the gas is always greater than that of the air, by reason of its greater mass and higher specific heat.

If part of the flue gas can be directed for other use ahead of the air heater, or if the air quantity can be increased by passing air for other purposes than combustion, through the heater, a better balance of gas temperature drop to air temperature rise will result and the economy of the air heater will be much improved.

In the storage system, flue gas may be taken ahead of the air heater or additional air may be passed through the air heater to meet the requirements of fuel drying.

In the direct-firing system any air or flue gas used for drying must be discharged to the furnace with the fuel and no improvement in economy of the air heater is effected. Furthermore, as the temperature of the air-coal mixture is limited to 185 F by reason of safety, it is usually necessary to reduce the air temperature to the mill by admitting some cool air. This will, of course, reduce the amount of air through the heater and adversely affect its performance.

STORAGE AND UNIT SYSTEMS. Nearly all the early installations of pulverized coal firing under steam boilers used the storage system. The complication of this system, particularly when separately fired coal dryers were considered necessary, imposed a serious handicap on the storage system in comparison with other methods of firing.

The direct-fired or unit system was developed for the purpose of simplifying and reducing the cost of a pulverized fuel fired system. Reduction in cost and space requirements is the chief advantage direct firing has over the storage system. That the difference in cost has been decisive is attested by the much greater number of direct-fired installations now in service.

The use of mill drying, which made direct firing possible, has, of course, also greatly simplified the storage system. The latter has inherently a higher efficiency than direct firing and also has certain advantages which should be evaluated and balanced against its higher cost. Differences in cost of the two systems will vary with local conditions. With the rising costs of fuel, the storage system will, on an economic basis, compare more favorably with the direct-firing system.

The Port Washington Station represents the ultimate in the development of the storage system and the results in combustion efficiency and overall station economy have fully justified the choice of that system.

In the foregoing, which is largely historical, it has been attempted to give some of the background of the development leading to present-day design. The furnace has had the most important rôle in this development. It has started as a "combustion chamber" wherein the fuel was given time and room to burn. It has now assumed other functions and today it is part furnace, part burner, part boiler and even part superheater.

Part Two—by E. M. POWELL†

DURING the earlier days of the design of pulverized coal-fired units, the primary consideration was to provide an efficient means for burning the coal. The only water cooling installed was that required to provide a convenient means of ash removal and to minimize the maintenance of the refractory walls. Year by year more water cooling was added until a few years ago Mr. Kreisinger's prophecy was fully realized with the design of a unit where the boiler was in reality wrapped around the furnace with little or no convection steam generating surface. Progress has now gone a step beyond that point with the demand for units designed for greater availability and higher load factor to be operated with a minimum of hand labor for keeping the unit clean particularly with the poorer quality of coal available. Possibly, the biggest change in operating conditions affecting design has been the use of high superheat and reheat. The point has now been reached where the method of firing and the proportioning of the entire steam generating unit is determined by the requirements of the superheater and reheater.

For example, there are now several units in process of design for 1000 F primary steam temperature and reheat temperature with 1500 psi at the superheater outlet. One of these is shown on Fig. 1. With the simple superheater and reheater arrangement shown, absorbing heat primarily by convection, the gas temperature drop between the furnace outlet and economizer inlet at the design capacity will be approximately 1300 F, allowing for a small drop across the upper ends of the water-wall tubes. Saturated steam enters the superheater at nearly 600 F

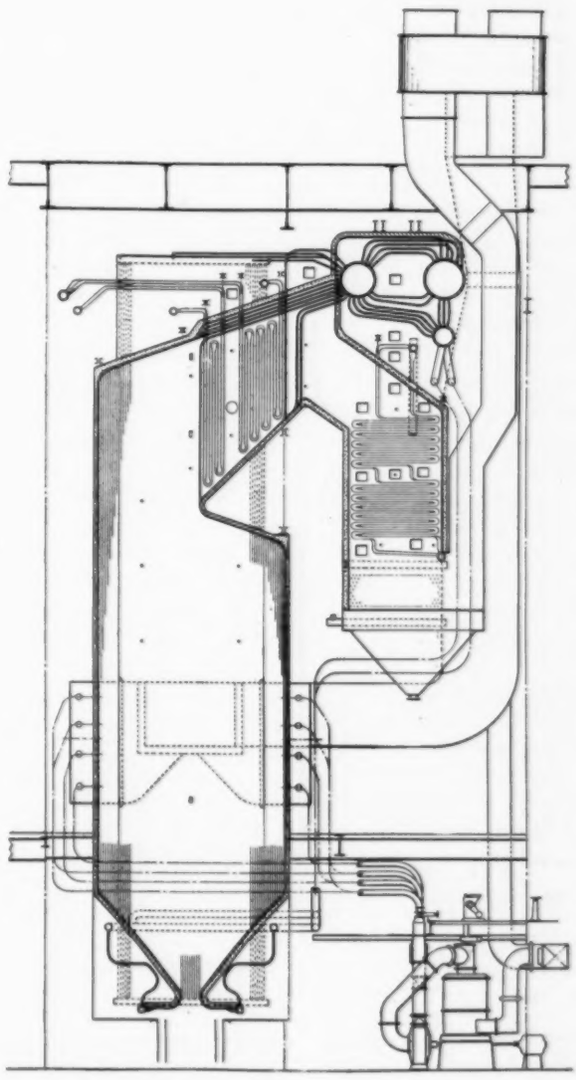


Fig. 1—Modern 1500-psi, 1000-F unit employing reheat

† Design Engineer, Combustion Engineering Company

and the steam entering the reheater is somewhat higher. In order to arrive at an economical design, the gas temperature entering the economizer cannot fall much below 800 F at the design capacity. This will require a gas temperature of 2100 F leaving the furnace.

With a conventional turbine design, the steam temperature to the reheater will be reduced as the rating is reduced. This will require a greater gas temperature drop through the reheater for a constant reheat temperature. The gas temperature entering the reheater, therefore, will vary only slightly with rating. With the usual burner design where heat is released in a fixed zone in the furnace, the furnace will absorb an increased percentage of the heat input as the rating is reduced, which will result in a considerable variation of gas temperature.

With high-ash, low-fusion coals such as are prevalent today and are apt to be more prevalent in the future, it is desirable to maintain the minimum furnace temperature at the design capacity which will satisfy the needs of the superheater and reheater. In order to maintain constant steam temperatures at lower load, the effectiveness of the furnace must be reduced at those loads. This can be accomplished by changing the distribution of fuel to the several burners or by varying the number of burners in service. Such procedures require increased firing capacity or a duplication of equipment and are a burden to the operating personnel, particularly if frequent changes are required.

The use of vertically-adjustable tangential burners will avoid such operating complications. So much has been written in the past and their use is so widespread that a detailed description of this method of firing is unnecessary at this time. Briefly, however, furnace temperature control is obtained in the following manner:

When the coal and air streams are directed downward toward the furnace hopper, the rate of heat absorption by the heating surface located in the lower furnace will be increased beyond that obtained with horizontal burners. Furthermore, with the increased length of gas travel provided, combustion will be completed at a point lower down in the furnace, thereby improving the efficiency of the upper water wall surface, which will result in a lower temperature of the gases leaving the furnace. Exactly the opposite effect will result from directing the coal and air upward, thus using the lower part of the furnace less effectively and forcing the flame closer to the top of the furnace which gives less time for heat absorption and a higher gas temperature leaving the furnace. Some quantitative data illustrating this process were collected at

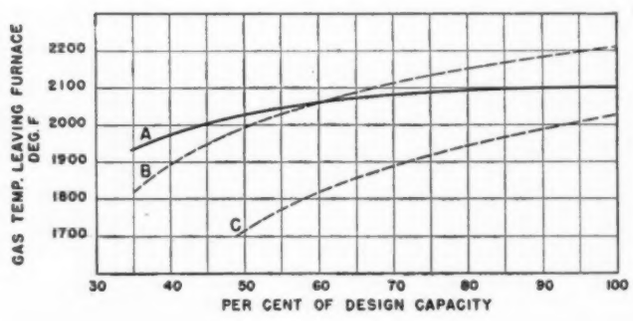


Fig. 2—Furnace exit gas temperatures with vertically-adjustable burners

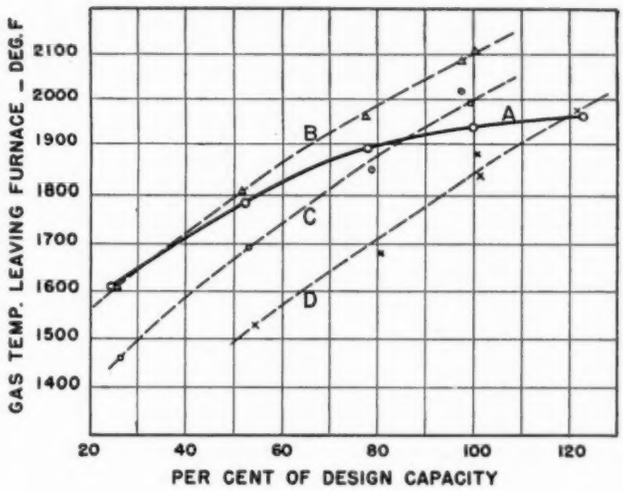


Fig. 3—Results of Havana tests

Tidd Station and presented to the Society last June by the Furnace Performance Factors Committee.

How this method of operation can be applied to the design of the reheat unit shown in Fig. 1 is demonstrated by the temperature curves in Fig. 2. Curve *A* represents the gas temperature leaving the furnace required to maintain 1000 F superheat and reheat temperature. At the design capacity both heaters require the same gas temperature leaving the furnace. As the rating is reduced, the temperature required by the superheater decreases with respect to the reheater. Supplementary control is provided for the superheater in the form of a desuperheater. The furnace temperature is, therefore, regulated to satisfy the needs of the reheater. Curve *B* represents the furnace exit gas temperature which can be obtained with the burners tilted 30 deg upward and Curve *C* with the burners tilted 30 deg downward. It will be noted that constant steam temperatures can be maintained down to 60 per cent of design capacity. Some additional margin of gas temperature control by tilting the burners downward has been retained to allow for variations of feedwater temperature depending on the number of stages of feedwater heating in service and to allow for changing coal characteristics that might affect the rate of ash accumulation on the furnace walls.

Tests were recently run at the Havana Station of Illinois Power Company, the purpose of which was to obtain sufficient data to prepare a similar set of curves. The results of these tests are shown on Fig. 3 plotted against per cent of design capacity. Curve *A* was plotted from data collected with the bypass damper closed and is the gas temperature leaving the furnace required to maintain a constant steam temperature of 900 F. Curves *B*, *C* and *D* are actual gas temperatures measured with the burners tilted upward 25 deg horizontal, and downward 25 deg respectively. These data demonstrate that with the variation of CO_2 and feedwater temperature which existed during these tests, the steam temperature can be maintained constant with the burners alone from 25 per cent of design capacity to an overload of 22 per cent or over a total range of ratings of 5 to 1.

The burner tilt mechanism at Havana is motor-driven, receiving its motivating impulse from the steam temperature control equipment. The bypass damper is con-

nected to the circuit to act as a supplementary control and open a fixed amount when the burners reach a downward tilt of 20 deg. After a given time lag, if the burners remain below 20 deg, the damper will open another step.

Fuels Performance at Port Washington Station

By W. A. POLLOCK*

CAREFUL, conservative furnace design has been one of the most important factors in sustaining favorable economy and reliability. With more than 50 per cent of the heat absorption occurring in the furnace of modern boiler units, a furnace possessing the versatility to burn low-grade, as well as high-grade, coal is essential. Changing coal markets require that coals varying greatly in nature and ash characteristics be consumed at various loads.

In the early days of pulverized fuel firing, prior to the introduction of water-cooled surfaces into the furnace, 13,000 Btu per cu ft of furnace volume per hour, with 13 per cent CO_2 in the exit gases, was a practical maximum if refractory maintenance was not to be excessive.

As furnace cooling, in the form of water screens and then water walls, was employed, the maximum heat release used in large units was increased to 25,000 and 30,000 Btu per cu ft per hr, and higher. Changing fuel characteristics during the war and resulting slag accumulations have caused an "about-face" in the thinking, and now the question often asked is, "How large a furnace shall it be?"

High Availability

Life-time availability records[1] for Units 1 and 2 at Port Washington are 94.9 per cent for the boilers and 93.5 per cent for the turbines. A 68 boiler-years availability record for the four high-pressure boilers and topping turbines at Lakeside Station was 94.5 and 96.5 per cent, respectively. Thus, high-pressure boilers are shown to be as dependable as turbines.

How well Port Washington was able successfully to burn the various coals furnished during the war and later is shown in part by the heat rates which Unit No. 2 averaged, 10,508 Btu per net kwhr in 1947, or a four-year average of 10,597 Btu.

That present coal quality is far below that of pre-war coals is general knowledge. Ash-fusion temperature decreased 150 deg and is within 57 deg of the designed average furnace temperature. Troubles from slag have been avoided only by frequent inspections of the furnaces and by acting upon reports of any slag found when removing ash. Ten-point CO_2 traverses across the boiler width each shift assist in locating hot areas, and serve as a guide to the operating personnel in making needed air-distribution adjustments.

After 15 months of operation on Unit No. 1, it was reported that the first boiler pass had never required lancing. Even with the lower ash-fusion temperatures of post-war coals, lancing has not been required regularly. Periods of several months often elapse between occasions when extensive lancing is necessary.

Only 0.12 per cent of the steam generated is needed for soot-blowing. This represents 12 Btu per kwhr increase in station heat rate. The only means of steam-temperature control, aside from flame positioning, is by this selective cleaning of heat-absorbing surfaces.

Load reductions at night have been used by some to explain the apparent self-cleaning of boiler furnaces, but at Port Washington lack of system load is normally the only reason for reducing load. These boilers have operated at full rating 16 to 18 hr daily and, on occasions, at full load for more than 48 hr. Continuous operating periods of 8 months have occurred. What practically amounts to one outage per year is now practiced, for one of the scheduled semi-annual outages on each unit is shortened to start at Friday noon and end Monday morning; the other semi-annual outage is ordinarily of 9 days' duration.

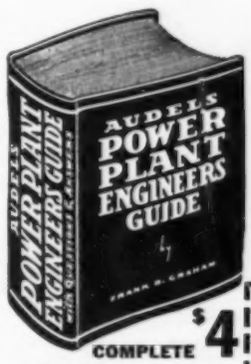
Carrying post-war loads with post-war coals, instead of the coals for which the station was designed, has resulted in extra equipment hours throughout the coal-handling section. The 12.9 per cent average ash in the 1947 coal accounted for much of the extra coal-storage and handling costs. Ash disposal costs in 1947 were approximately 50 per cent greater than in 1940.

The average moisture in the coal to the pulverizers was 7.4, with a maximum of 14.3 per cent. To dry this higher moisture coal properly, a higher gas temperature must be used. Flue gas at 830 F has been employed to dry this coal on No. 1 unit where 830-F flue gas entering the air heater is available. On No. 2 unit the flue gas to the air heater averages 700 F, and the life-time average output of its mills has been 0.9 ton per hour lower. Flue gas for mill drying on the units now under construction will be taken from high in the last pass to obtain higher temperature gas in an effort to raise mill capacity. Flue gas temperature to the mills will be controlled as on the other units by tempering with gas from the air-heater outlet.

Higher maintenance on pulverizers and draft fans has resulted from the poorer quality coal.

* Senior Test Engineer, Wisconsin Electric Power Company.

[1] Lack of space here prevents reproduction of the tables included in Mr. Pollock's paper.—EDITOR.



COMPLETE $4

PAY ONLY $1 A MO.

Get this information for Yourself. Mail Coupon Today. No Obligation Unless Satisfied. ASK TO SEE IT.

ENGINEERS ★
INFORMATION ★
QUESTIONS and ANSWERS ★

JUST OUT! Audels Power Plant Engineers Guide. A complete Steam Engineers Library covering Theory, Construction & Operation of Power House Machinery including Steam Boilers, Engines, Turbines, Auxiliary Equipment, etc. 65 chapters, 1500 Pages, over 1700 Illustrations. 1001 Facts, Figures and Calculations for all Engineers, Firemen, Water Tenders, Oilers, Operators, Repairmen and Applicants for Engineer's License.

FREE TRIAL!

AUDEL, Publishers, 49 W. 23 St., New York 10

MAIL AUDELS POWER PLANT ENGINEERS GUIDE for free examination. If O.K. I will send you $1 in 7 days; then remit $1 monthly until price of $4 is paid. Otherwise I will return it.

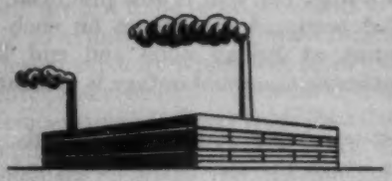
Name_____

Address_____

Occupation_____

Employed by_____ COM

Let's make your COAL buying Easier!



WHAT YOU WANT WHEN BUYING COAL is quality fuel that has been carefully prepared to suit your needs. You also want this high-grade coal to be priced economically for specific jobs. And further still you want coal shipments to be scheduled and delivered as promised.

WHAT WE OFFER IS COMPETENT AND COMPLETE sales and service that answers these wants and needs. Whether you are the buyer for a railroad, industry, public utility, municipality or a retailer, you can depend on us to meet your exact demands for quality coal at the least cost. We offer not only *consistently* high-grade coal and service but also engineering experience and counsel to advise you on the best coal for a specific job.

WE CAN FILL YOUR WANTS. The decision is simple. Do you want competent coal sales service . . . or do you buy the cheapest way you can and take a chance on your fuel needs? Call or write for information.

Sales offices are located in the principal cities.

SNYDER & SWANSON, INC.

COAL MERCHANDISERS

Main Office: PITTSBURGH, PA.

SNYDER & SWANSON COAL

BRANCH OFFICES

- CLEVELAND
- BALTIMORE
- NEW YORK

Shipment By: RAIL · LAKE · TIDEWATER

CORROSION:

Its Effect in Boiler Systems—Part II

Part I of this article appeared in the May issue and dealt with theories of corrosion, the action of oxygen, and its removal from the system. The present article takes up carbon dioxide, ammonia, hydrogen sulfide, acidity and certain physical factors, discussing corrective measures for each.

By ROBERT L. REED
Chemical Engineer, W. H. and L. D. Betz

Carbon Dioxide

SOURCES OF CARBON DIOXIDE: Carbon dioxide is another non-condensable gas creating a favorable environment for corrosive action. Underground formations and organic materials impart this gas to water and, consequently, well sources contain generally higher concentrations than surface supplies. Nevertheless, atmosphere contaminated with industrial gases can elevate the quantities found in surface waters.

The major portion of carbon dioxide in the steam cycle, however, does not result from quantities introduced in the dissolved state by the feedwater since this gas can be removed almost entirely by efficient deaeration. Rather, decomposition of the feedwater bicarbonate and carbonate alkalinity under boiler temperature represents the principal source. This condition applies particularly with utilization of sodium zeolite softeners inasmuch as the process converts practically all of the natural calcium and magnesium bicarbonate to sodium bicarbonate. The latter salt, being very unstable at boiler temperatures, decomposes to form boiler water alkalinity concentrations in accord with the following:

$$\underset{\text{Sodium bicarbonate}}{2NaHCO_3} + \underset{\text{Heat}}{\Delta} = \underset{\text{Sodium carbonate}}{Na_2CO_3} + \underset{\text{Water}}{H_2O} + \underset{\text{Carbon dioxide}}{CO_2\uparrow}$$

The sodium bicarbonate breakdown yields not only sodium carbonate, but also carbon dioxide. Under further heat action, sodium carbonate decomposes and expels additional carbon dioxide:

$$\underset{\text{Sodium carbonate}}{Na_2CO_3} + \underset{\text{Water}}{H_2O} + \underset{\text{Heat}}{\Delta} = \underset{\text{Sodium hydroxide}}{2NaOH} + \underset{\text{Carbon dioxide}}{CO_2\uparrow}$$

Laboratory experiments have demonstrated that the actual percentage of decomposition within boilers depends upon several conditions, with temperature indicated as the main factor. For average practical purposes, however, 100 per cent bicarbonate alkalinity and 80 per cent sodium carbonate decomposition can be assumed. Based on those empirical values, each 100 parts of sodium bicarbonate (as $CaCO_3$) in the feedwater will yield 79 parts carbon dioxide (as CO_2) in the steam, while each 100 parts sodium carbonate (as $CaCO_3$) will evolve 35 parts carbon dioxide. With the absence of internal boiler water conditioning or with a method of correction not requiring excess soluble phosphate, a certain percentage of carbon dioxide would be used in precipitating calcium carbonate. With calcium carbonate deposition prevented by a phosphate type of internal water treatment, steam would be expected to contain practically the entire amount of carbon dioxide available through alkalinity breakdown. Naturally, relatively small quantities of carbon dioxide would be lost through blowdown, but it is interesting to note that increased blowdown increases the feedwater demand and this would consequently elevate the content of the gas in the steam.

Several other factors can permit introduction of carbon dioxide into the steam phase. Acid treatment and hydrogen zeolite softening of make-up waters result in the formation of carbonic acid which must be liberated in an aeration chamber or degasifier. Faulty operation of degasifying equipment naturally permits the development of high carbon dioxide concentrations in the steam and condensate systems. Soda ash when employed without proper control for softening by the lime-soda ash process or when improperly applied for the achievement of desirable boiler water alkalinities also contributes the corrosive gas, with the decomposition within the boiler proceeding as outlined.

ACTION OF CARBON DIOXIDE: Feedwater piping, valves, heat-exchangers and other similar equipment suffer attack when the corrosive nature of the feedwater has been increased by appreciable amounts of carbon dioxide. Corrosion from this gas directly within boilers and below the water line is not encountered frequently, providing ample alkalinity concentrations develop. In the steam phase at points of condensation and in the condensate cycle, however, concentrations of the gas dissolve in the water to create carbonic acid as follows:

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} = \underset{\text{Carbonic acid}}{H_2CO_3}$$

From a practical standpoint moisture must be present for the gas to exert its corrosive force, so wastage of metal will occur to a lesser degree with superheated steam until

Fig. 9—Condensate line corroded by carbon dioxide

sufficient work has been accomplished for the steam to become desuperheated and wet.

Attack by this gas in feedwater lines and boilers is evidenced by general roughing of the metal while the action of the corrosive medium upon steam and condensate lines is manifested principally in the form of grooving along the bottom, although, as a general rule, any portion of the metal in contact with the condensate will suffer attack. Fig. 9 illustrates the effect of carbon dioxide upon a condensate return line, with the characteristic sharp channeling or grooving indicated distinctly.

Carbon dioxide concentrations of 5.0 ppm or less seldom prove troublesome, except where large amounts of steam are involved. Stratification, however, may occur at traps or where lines run on a horizontal incline, thereby establishing considerably higher quantities of the corrosive gas in such areas than present elsewhere in the system. Further, the rate of corrosion does not depend necessarily upon the quantity of the gas alone, but also becomes a function of the solution flow rate. That is, as much corrosion takes place with a low carbon dioxide concentration and a high flow rate as with large quantities of the gas and a low flow rate. An actual limitation of the permissible gas concentration cannot, therefore, be established as a criterion. Experience has proved also that corrosion from carbon dioxide is increased materially in cases where pulsating flow occurs. Laboratory experiments have revealed that oxygen present in an aqueous solution containing carbon dioxide produces an environment two to ten times more corrosive than occurs with an equal carbon dioxide concentration, but oxygen absent entirely. The pipe section illustrated by Fig. 10 was removed from a return line after a relatively short service period carrying condensate containing both oxygen and carbon dioxide.

Failures frequently take place at threaded joints since less metal is present to corrode and unrelieved stresses set up in threading tend to assist the corrosive environment. Quite frequently, elbows and bends also show evidence of attack, since impingement of the aqueous solution will accelerate the corrosive force. Iron is recognized as the common metal affected pronouncedly by this gas, but attack of copper can occur also. Nevertheless, reasonable service can be expected normally with red brass and acid-resistant brass.

Corrosion products formed in return condensate systems frequently are carried by the returns to the feedwater and subsequently to the boilers. Consequently, metal wastage becomes detrimental not only from the

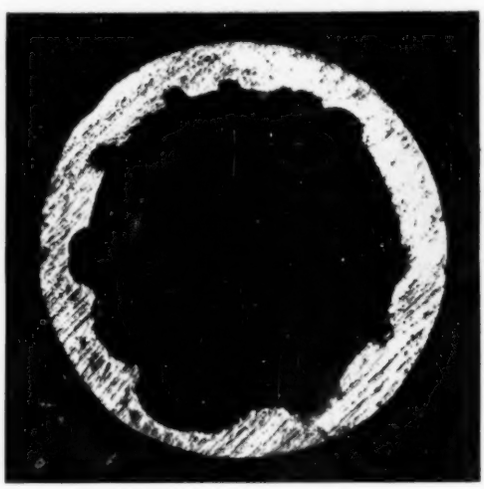


Fig. 10—Attack by oxygen and carbon dioxide

standpoint that failure of ferrous and non-ferrous metals occurs, but also corrosion products can be deposited in heaters and valves and interfere with proper operation of feedwater regulating devices. In addition, iron oxide in boilers can act as a binder for precipitated incrusting solids, thus increasing the potential for scale formation.

TABLE C—REDUCTION OF CARBON DIOXIDE IN STEAM THROUGH ACID TREATMENT

(All expressed in parts per million, except percent blowdown)

	Raw	Sodium Zeolite Feedwater	Boiler Water*	Steam	Acid-Treated Sodium Zeolite Feedwater	Boiler Water†	Steam	Sodium Hydrogen Zeolite Feedwater‡	Boiler Water	Steam
Hardness, as $CaCO_3$	110	0–6	0		0–6	0		0–6	0	
Calcium, as $CaCO_3$	77	0–4	0		0–4	0		0–4	0	
Magnesium, as $CaCO_3$	33	0–2	0		0–2	0		0–2	0	
P. alkalinity, as $CaCO_3$	0	0	900		0	450		0	450	
M. O. alkalinity as $CaCO_3$	100	100	1000		28	500		14.5	500	
Sulfate, as SO_4	22	22	220		90	1620		22	770	
Chloride, as Cl	8.0	8.0	80		8.0	144		8.0	280	
Silica, as SiO_2	6.0	6.0	60		6.0	108		6.0	210	
Phosphate, as PO_4	...	...	45		...	45		..	45	
Dissolved solids, calc.	208	219	1510		199	3359		76	2532	
Total solids, calc.	...	...	1570		...	3467		..	2742	
Blowdown, %	...	...	10.0		...	5.6		..	2.9	
Carbon Dioxide, as CO_2	...	...	....	87.7	...	....	23.4	..	....	11.8

Conditions:

* Boiler water total alkalinity permitted to develop above 20% dissolved solids limit suggested by American Boiler Manufacturer's Association in stipulations for high quality steam.

† Total solids restricted below 3500 ppm limitation of A.B.M.A. for boilers up to 300 psi gage.

‡ 34.5% sodium zeolite and 65.5% hydrogen zeolite softened water.

REMOVAL OF CARBON DIOXIDE: As in the case with oxygen, correction of corrosion problems attributed to carbon dioxide basically requires reduction in the quantity of the gas permitted to enter the system. Dissolved carbon dioxide present naturally in the raw makeup can be reduced by aeration, if sufficiently high concentrations are present to justify installation of necessary equipment. Proper type feedwater heaters provide also a means by which the dissolved gas can be removed, since elevation of the solution temperature releases this gas in a manner similar to oxygen. In certain cases, an alkaline agent, such as caustic soda, may be employed to neutralize the acidity due to carbon dioxide and thus alleviate attack in feedwater piping and equipment. However, appreciable concentrations of the gas will require the feed of large quantities of a chemical corrective and the feedwater solids might possibly be increased above a limit considered desirable. Proper adjustment of boiler water alkalinities will prevent a corrosive environment from the gas in steam generators.

Feedwater temperature elevation with an efficient type heater provides a method of partially breaking down the feedwater bicarbonate and carbonate concentrations, thus achieving some reduction of combined carbon dioxide. The major portion of decomposition will occur, nevertheless, at the boiler operating temperature, as discussed previously. Acid treatment or hydrogen zeolites followed by degasification are two methods applicable in certain cases for reducing externally the feedwater alkalinity concentration which, in turn, will reduce the quantity of carbon dioxide evolved with the steam.

Data contained in Table C illustrate feedwater alkalinity reduction achieved by such external processes and the lower steam carbon dioxide content consequently resulting. In the selection of equipment for external softening, not only the degree of hardness removal should be considered, but also resultant feedwater characteristics, since the carbon dioxide in the steam will vary in proportion to the feedwater alkalinity. Sodium zeolite softening does not alter the concentration of the influent alkalinity, so the lime-soda ash process or parallel sodium-hydrogen zeolite units become more desirable with feedwater of relatively high natural alkalinity.

Organic amines have been developed which volatilize with the steam and thereby neutralize the acidic nature of carbon dioxide. Such materials must be fed to the system continuously in order to regulate the steam pH to an optimum range. Elevation of the pH retards iron corrosion, but protection has not been demonstrated with materials such as zinc, aluminum, tin and lead. A volatile material such as ammonium sulfate $(NH_4)_2SO_4$, may be employed in cases where copper-bearing alloys are not present in the system, although most applicable amines do not attack copper.

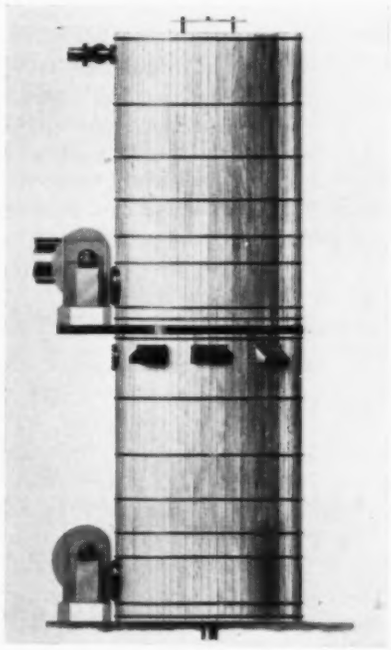
While a large portion of the corrective amine would recirculate in cases where open or deaerating type heaters do not pre-heat the returns, a loss of amine would be encountered due to volatilization in vented heating equipment. In general, favorable results have been achieved at times with some types of amines, but the cost of those available at present frequently limits application. Consequently, external reduction of carbon dioxide often remains the more economical corrective step.

Considerable research work is being conducted on the use of materials other than amines for the prevention of steam and return line corrosion. Although all test data are not yet complete and ready for publication, rates of corrosion prevention as high as 80 to 85 per cent have been obtained under operating plant tests conditions with chemical treatment of a film-forming nature.

Soda ash employed frequently for the development of favorable boiler water alkalinity concentrations should be replaced by caustic soda when carbon dioxide represents a problem. Lime-soda ash softener effluent balances should be regulated closely to prevent excessive carbonate alkalinity in the effluent.

Ammonia

SOURCE AND ACTION: Ammonia present in water generally exists in the forms of albuminoid ammonia and free ammonia. The former, consisting of organic bound nitrogen principally, must be decomposed first to ammoniacal nitrogen, while free ammonia is available for immediate distillation with the steam.



Courtesy Cochrane Corporation

Fig. 11—Hydrogen sulfide degasifying apparatus

The most frequent chemical attack induced by ammonia involves solution of copper or copper alloys by possibly forming a highly soluble cupric-ammonium ion. Not only are the affected parts damaged, but the copper dissolved by this action may be deposited possibly elsewhere in the boiler system. Copper deposits finding their way into the boiler system through corrosion of valves, surface condensers, water column parts, fittings, etc., can set up a galvanic cell when in contact with boiler water. Copper, being in the electropositive group of the Electro-chemical Series, promotes the tendency for the iron to become anodic, thus permitting ferrous ions to enter the solution. Therefore, wastage of metal promoted by a certain cause in one section of the boiler sys-

tem can bring about corrosion in an entirely different location by an altogether dissimilar reaction. Rarely, however, has this action been proved definitely to be the basic cause of corrosion in boilers. In addition to attacking copper alloys, ammonia may damage nickel and zinc equipment.

Although reasonable ammonia concentrations seldom promote corrosion difficulties, no definite maximum concentration can be regarded as a criterion in evaluating whether or not the gas will prove troublesome. The flow rate must be considered also and high local concentrations of the non-condensable gas may develop in certain sections. Drips from after-condensers generally contain appreciable ammonia and frequently should be allowed to pass on to waste.

REMOVAL OF AMMONIA: Mechanical separation of ammonia from solution is possible through a process of scrubbing the water with high quality steam in a very high tray stack. A large percentage of reduction is generally difficult due to the high solubility of ammonia, but decreases from 5.0 ppm to 0.01 ppm have been achieved. The process is not employed frequently, however, due to the expense of the high steam venting required. Several other removal methods have been attempted from time to time and the adaptability of chlorine has been realized only in recent years. It is believed this agent reacts with ammonia to form nitrogen and hydrochloric acid, as illustrated by the postulated equation:

$$3Cl_2 + 2NH_3 \ldots\ldots 6HCl + N2$$

Chlorine Ammonia .... Hydrochloric acid Nitrogen

Theoretically, 1.0 part ammonia requires the feed of 10 parts chlorine, but actual application has indicated as high as 1 : 25 ratio may be necessary. The reaction speed and degree of completion is a function of the pH value (6.5–8.5 recommended), the temperature and the contact time. Sufficient chlorine must be injected so as to pass the "break-point," as determined by the Laux Flash Test which specifies 85–100 per cent of the yellow color must develop at once after addition of orthotoline reagent. Provision must be available for excess chlorine removal by such equipment as an open or deaerating type heater inasmuch as free chlorine might impart a corrosive quality to the boiler feedwater.

Hydrogen Sulfide

SOURCE AND ACTION: Hydrogen sulfide may be present in well supplies, particularly in the vicinity of "sour gas" oil fields. Some polluted surface sources also contain this gas which is distinguished easily by the "rotten egg" odor. Excessive hydrogen sulfide concentrations should be avoided since the gas exhibits an aggressive tendency toward iron, steel, copper and copper alloys, even in the absence of oxygen.

REMOVAL OF HYDROGEN SULFIDE: Removal of hydrogen sulfide is accomplished usually by aeration and elimination of this gas proceeds most completely at a pH below 6.5. The necessary pH can be obtained by a proportional feed of acid or by introducing carbon dioxide from flue gases. With one type of equipment available, the raw water is sprayed over a bank of wooden trays while acid is injected either with the water being treated or at various sections of the equipment. The water becomes scrubbed by a counter-current of air forced in at the bottom and vented at the top. In apparatus such as illustrated by Fig. 11, a double stack is employed with a separating water seal. The influent water mixes with a counter-current flow of carbon dioxide in the top tray section and a certain percentage of the hydrogen sulfide is removed. In the lower section of similar design as the top area, a counterflow of air effects removal of carbon dioxide and residual hydrogen sulfide. Adaptability and design of such a process depends upon particular circumstances surrounding the contemplated application.

Acidity

All waters contain both hydrogen and hydroxyl ions, with the solution pH value indicating the relative concentrations of active ions. The pH scale ranges

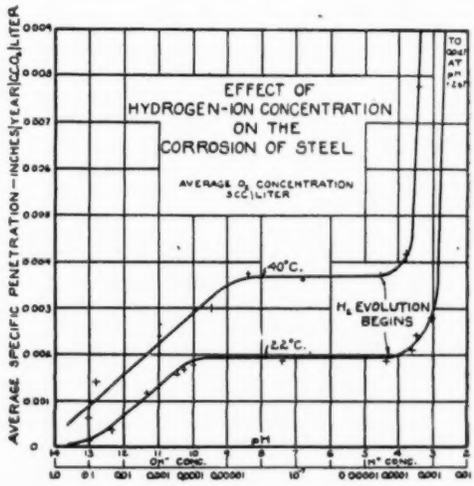


Fig. 12—Effect of hydrogen-ion concentration on the corrosion of steel (after Speller)

from 0 to 14.0 and the value of 7.0 denotes that the hydrogen and hydroxyl ions exist in equal quantities or balance one another, thus creating a neutral solution. Waters in which hydroxyl ions exceed the hydrogen ions are alkaline, with the alkalinity increasing as the pH approaches 14.0. On the other hand, pH values below the neutral 7.0 point signify that the hydrogen ions exceed the hydroxyl concentration, with the acidity increasing as the pH decreases. Inasmuch as the pH scale is a logarithmic function, each unit of change in pH shows a tenfold variation in the active acidic or alkaline solution tendency.

Since the progress of corrosion requires the release of hydrogen ions, where fewer hydrogen ions are available in the aqueous solution the quantity of metallic ions allowed to enter solution is reduced. That is, acidity generally increases the rate and extent of corrosion, although it is not the fundamental cause of corrosion, since metal wastage can occur in the absence of acidity. In general, as shown by Fig. 12, lower pH accelerates corrosive attack.

Process waste, pickling plant waste waters and mine drainage containing free sulfuric acid often contaminate makeup sources and provide an environment for corrosion. Sulfuric acid can be introduced into the raw water by atmospheric contamination also.

Attack by an acid solution upon copper-zinc alloys produces a condition termed dezincification. That is, the environment exerts its corrosive force so as to remove the zinc, but leaves the metallic copper in a soft, spongy-like matter. The equipment attacked often retains the original shape temporarily until reduced strength permits failure. Degraphitization identifies similar action on iron and steel products. Acid attack upon feed lines is not infrequent, but proper control over boiler water alkalinities in a well-regulated plant seldom permits an opportunity for this type action in steam generators.

Adjustment of feedwater pH to an optimum range can be accomplished frequently by the introduction of soda

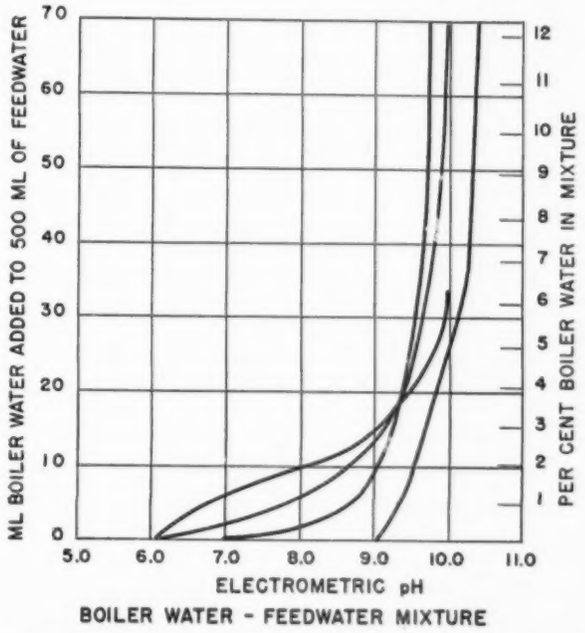


Fig. 13—Typical increase in feedwater pH with boiler-water recirculation

ash or caustic soda, but such a practice is not always applicable due to the resultant increased solids for the feedwater. Further, the tolerable boiler water alkalinity can limit the quantity of alkali that may be fed to the feedwater. Recirculation of boiler water to the feed pump suction or heater storage section represents another method that can accomplish pH adjustment readily. With unbuffered feedwater, only relatively small amounts of boiler water (usually 1.0–2.0 per cent) are required to produce an appreciable increase in pH. Fig. 13 illustrates the influence of the boiler water in elevating the feedwater pH. Care in control must be exercised inasmuch as pH values substantially above 8.6 are detrimental to bronze pump impellers. Application is limited often to plants receiving high percentage returned condensate since the necessary recirculation rate may be considerably greater than feasible in cases with high makeup water demand.

Influence and Correction of Physical Factors

BI-METALLIC CORROSION: Bi-metallic, or galvanic, corrosion occurs when two dissimilar metals are coupled together, with the magnitude of attack depending upon the metals involved and the environment. The metal standing with the greater electronegative potential in the electro-chemical series will go into solution, or as a specific example, when copper and iron are joined, the copper becomes cathodic and the iron anodic to suffer attack. Sometimes, the extent of corrosion depends upon the arrangement of the metals. That is, little corrosion of iron will be noticeable when a copper alloy fitting is included in an iron pipe line, but pronounced wastage of the iron may occur with an iron fitting inserted in a copper line.

The most positive corrective measure, if the action is severe, requires installation of equipment fabricated entirely of one type of metal. If such a step is not considered feasible, a short pipe with unions should be employed on each side of the attacked area for ready replacement. This type of action in boiler systems cannot be corrected by the use of chemical treatment.

ELECTROLYSIS: High-tension wires in close proximity to piping or equipment will induce stray electrical currents, thereby causing electrolysis. Proper grounding of the current source, grounding of metallic conduits and relocation of high-tension lines paralleling water or steam lines represent corrective measures.

The physical appearance of metal wastage induced by electrolysis displays a likeness to that caused by oxygen. Bi-metallic corrosion brought about by dissimilar metals promotes corrosive attack in the immediate vicinity of the coupling point only, but electrolysis actuated by stray currents can appear some distance from the actual location of current leakage. Inasmuch as very few cases of power plant corrosion problems have been attributed definitely to electrolytic action, complete elimination of oxygen must be achieved prior to assuming that the trouble has been influenced by electrolysis.

MANUFACTURE: Although a discussion of the aqueous environments creating corrosion as encountered in power plant operation is the prime purpose of this article brief mention of the effect of manufacture should be made. Physical characteristics of the metal as brought about by manufacturing processes appear to have a pronounced influence upon the rate and nature of corrosion, although this has been a controversial subject among authorities for a long time.

Experience indicates that high sulfur content in pig iron tends to accelerate corrosion in some solutions. However, manufacturers strive to produce a finished product low in residual sulfur, with excess sulfur usually signifying faulty furnace operation. Irregular distribution of non-metallic slag or coke or any non-uniformity within the metal due to the annealing method are factors believed to accelerate corrosion in localized areas. Casting sand, filings, rust or other forms of debris seem to promote pitting adjacent to their position, with the uncovered portion cathodic and attack taking place at the covered anodic area. However, the majority of corrosion problems encountered actually have been traced to the environment rather than inferior quality of metal.

Mill scale is another foreign substance which has often given rise to corrosion. With this material (magnetic iron oxide), a film develops, but any break in the barrier permits contact of the water and the metal. Pitting, therefore, progresses by the metal becoming anodic to the mill scale (Fe_3O_4) in the presence of an electrolyte, such

as boiler water. Removal of the oxide involves such treatment as sand-blasting or pickling with acid.

Polished surfaces resist attack much better than rough metal and cast iron withstands corroding media better than rolled iron or steel. Possibly superior adherence of a protective rust coating to cast iron than to the other two metallic materials accounts for the cast iron being more stable.

Cold working of metal through operations such as flaring tube ends or punching rivet holes has been a condition indicated as promoting corrosion progress. Boiler designs sometime prohibit free expansion, so tubes might be subjected to excessive bending. Several cases of pipe failure at threads demonstrate that the corrosive tendency becomes more pronounced at areas where internal stresses are not relieved completely.

Fig. 14 illustrates a section of a steel line carrying water rendered corrosive by oxygen. Severe metal wastage occurred at the area in proximity of the threads, but considerably lesser attack resulted elsewhere in the line. Sudden chilling of boiler tubes by lancing or over heating through welding represent two other physical factors indicated as the primary cause of failure. Any section of equipment under stress, therefore, can be considered vulnerable to attack.

Stress fatigue thus produced often penetrates the corroded metal with circumferential, deep notches. Actually, metal wastage at stress points can be induced by either chemical or physical factors. Therefore, if at all possible, reference to such corrosion should identify it as corrosion-fatigue or physical-fatigue. When the attacked area subjected to stress is in contact with a corrosive environment, the term corrosion-fatigue should be employed. On the other hand, physical-fatigue

Fig. 14—Pronounced corrosion at pipe threads by oxygen

identifies cracks developed through stress loads being applied repeatedly in the absence of a corroding medium. The attack will appear in the form of cracks across the grain structure, but not necessarily along the grain boundaries. Physical characteristics of the corroded area as observed through microscopic examination would not be dissimilar in either case and the underlying cause can be determined only by a study of circumstances surrounding the problem.

INTERCRYSTALLINE CRACKING: The scope of this paper is not sufficient to justifiably discuss caustic metal embrittlement in detail, but brief mention will be made as this phenomenon has been referred to as a form of corrosion.

Stress fatigue as discussed previously becomes manifest as cracking across the grain structure of the metal, but with intercrystalline cracking the attack occurs along the

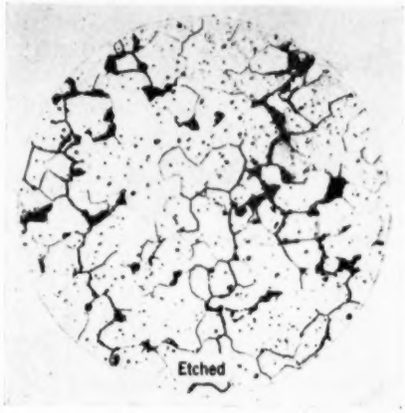


Fig. 15—Intercrystalline cracking of boiler steel

grain boundaries, as the identifying term implies. Fig. 15 depicts the characteristic manner in which the attack follows the borderline between the granular structure of the metal.

Boiler waters usually contain relatively low hydroxyl concentrations. Nevertheless, leakage at a point under stress and subsequent water evaporation permit locally high sodium hydroxide concentrations to develop, which then proceed to attack the metal. Research has demonstrated that no one hydroxide limit can be considered a criterion to apply in all cases and a boiler water analysis alone should not be considered when predicting the likelihood of embrittlement. Thus, good practice dictates the advisability of investigating the potential for this condition to exist. This can be accomplished readily by means of the embrittlement detector designed and developed by the United States Bureau of Mines which permits boiler water to pass constantly over a test specimen under stress. An initial test is generally of 30 days' duration followed by a 90-day confirmatory run. In such a manner, circumstances which could cause cracking within the boiler will be reproduced in an accelerated fashion. Examination by a competent laboratory following further stressing of the specimen bar will indicate clearly whether or not the boiler water possesses embrittlement tendencies under conditions of the test.

Many waters have natural inhibitory properties and require no further treatment to prevent embrittlement. The maintenance of certain sodium sulfate-alkalinity in the boiler water has shown value in inhibiting the intercrystalline cracking tendency in some cases, but this corrective method has lost favor recently to the more widely applied practice of developing optimum sodium nitrate-sodium hydroxide ratios. This latter method has proved successful not only in stationary application, but in locomotive service also. Other materials such as various tannins, waste sulfite liquor, chromates, lignin, etc., have been applied, but none has demonstrated the consistent protection afforded by sodium nitrate.

FLOW RATE: Velocity of flow will affect emphatically the progress rate of corrosion. With low flow rate, little of the water passing through a pipe actually contacts the walls, but in cases of high velocity or pulsating flow, the turbulence created causes the solution to reach the pipe sides, especially at bends, and the motion of the liquid thereby breaks any protective bond formed upon the metal surface. Tests have illustrated that any oxygen present in the aqueous solution is more completely used when turbulence occurs than with a quiescent condition, thus signifying more rapid advance of corrosion with turbulent conditions. As previously mentioned in discussing carbon dioxide and ammonia, the flow rate can affect the metal wastage rate as much as the concentration of the corroding gas present.

PROTECTIVE COATINGS: Protective coatings, such as bitumastic paints, have merit in providing insulation against corrosive attack, but proper application is of utmost importance for effective results. An absolutely clean metal surface must be prepared by wire-brushing or possibly sand-blasting before painting. Otherwise, a positive bond will not be achieved and cracks will develop quickly. Should the coating be destroyed in spots, corrosion will be accelerated in the form of localized pits which without doubt would be more detrimental than general corrosion which might have taken place in the absence of paint. Application is limited usually to tanks, receivers and boiler drums due to the inaccessibility into interiors of pipes and tubes. Rubber and synthetic materials, such as plastics, have received application recently also, with satisfactory service resulting. However, temperature and the alkaline nature of boiler water might be detrimental to their stability, hence limiting the use of such products.

Conclusion

Corrosion can occur from either chemical or physical factors, or a combination of several conditions can contribute to the cause of metal wastage. The proper solution to any problem, therefore, requires close study and correct evaluation of all existing chemical as well as physical conditions. Considerable time and expense have been expended in the study of the corrosion phenomenon, yet numerous types of corroding action remain unexplained. Investigations for the economical correction of the expensive corrosion problem should be conducted only by those qualified through extensive experience. Once corrective steps have been established, close control of conditions must be exercised to prevent recurrence.

REFERENCES

1. Betz, W. H., and L. D., *Betz Handbook of Industrial Water Conditioning*, Philadelphia 24, Pennsylvania.
2. Creighton, H. Jermain, *Principles of Electrochemistry*, John Wiley & Sons, Inc., New York, Vol. I, 2nd Ed., 1928.
3. Evans, Ulick R., M.A., D.Sc., *Metallic Corrosion Passivity and Protection*, Longmans, Green and Company, New York, 2nd Ed., 1946.
4. Getman, F. H., Ph.D., and Daniels, Farrington. *Outlines of Theoretical Chemistry*, John Wiley & Sons, Inc., New York, 6th Ed., 1937.
5. Griffin, A. E., "Chlorine Takes the Bite Out of Ammonia," *Power*, **89**, 7, 92 (1945).
6. Speller, Frank N., D.Sc., *Corrosion—Causes and Prevention*, McGraw-Hill Book Company, Inc., New York, 2nd Ed., 1935.
7. Vande Bogart, L. G., *Combating Corrosion in Industrial Process Piping*, Crane Company, Chicago, Illinois. Paper 408 (May 1939).

ARMSTRONG
Forged Steel
STEAM TRAPS

FOR ANY PRESSURE!

MAXIMUM pressures for Armstrong traps vary from 450 p.s.i. for No. 312 to 2400 p.s.i. for the No. 615. All high pressure requirements of modern plants can be met easily.

The trend in modern engineering is to get away from cast iron fittings. Armstrong Forged Steel Traps fit in perfectly with these trends, and offer the additional advantage of automatic condensate drainage. Prices are reasonable, and the extensive line makes it easy to select a trap that will fit individual requirements.

The fact that Armstrong Forged Steel Traps are well suited to high pressure applications does not eliminate them from the low and medium pressure field—quite the reverse. Operation on lower pressures is quick and efficient, and engineers like the resulting high factor of safety.

The Armstrong Steam Trap Book contains valuable information on steam trap selection, installation, and maintenance. Data, charts and graphs on current trapping practice are included. Send for a copy today.

ARMSTRONG MACHINE WORKS

814 Maple Street
Three Rivers,
Michigan

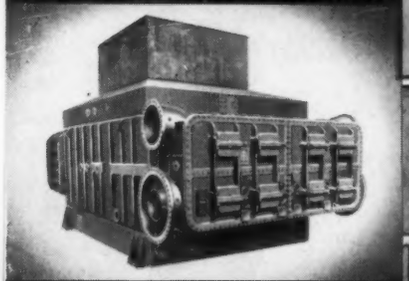
ARMSTRONG STEAM TRAP

Factory Trained Representatives in Principal Cities

SHAPING INDUSTRIAL PROSPERITY

THROUGH GENERATING STATIONS

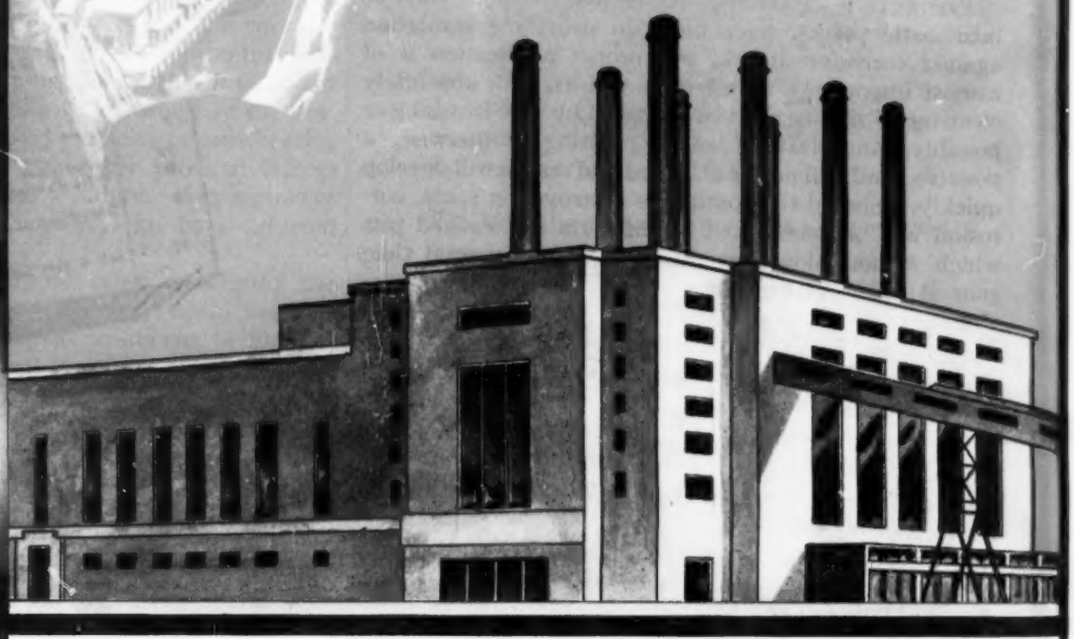
I-R Pumps for Boiler Feed System, Circulating, Condensate and General Service



I-R Condensers—Surface, Barometric and Ejector Jet Types

I-R Compressors for Instrument Control, Soot Blowing and General Service

I-R Portable Compressors and Air Tools for Service, Maintenance and Construction



Equipment made by Ingersoll-Rand was saving manpower and reducing costs eleven years before the first electric generating station took shape in 1882. Since then, Ingersoll-Rand products have been closely identified with many phases of the electrical industry.

During these 66 years electric generating stations have been indispensable in the Shaping of our Industrial Prosperity. Here is an industry financed by a million stockholders, manned by a quarter-million employees, expending a billion-a-year for fuel, maintenance and construction, serving 36 million customers—and market saturation is nowhere in sight.

Machinery built by Ingersoll-Rand is serving in most of the steam-driven generating stations. It has helped to build these plants and most of the famous dam projects for hydroelectric stations.

I-R Centrifugal Boiler Feed Pumps for pressures up to 3000 pounds per square inch—I-R Circulating, Condensate, Drip, General Service Pumps—Ingersoll-Rand Steam Condensers of all types and sizes—Diesel and Gas Engines—Compressors for instrument control and soot blowing—I-R Stationary and Portable Compressors and air-driven Rock Drills and Tools for excavation, tunneling, plant maintenance and servicing.

Ingersoll-Rand

11 BROADWAY, NEW YORK 4, N. Y. 192-14

AIR & GAS COMPRESSORS • AIR TOOLS
TURBO BLOWERS • PUMPS
REFRIGERATION • ROCK DRILLS
VACUUM EQUIPMENT • GAS & OIL ENGINES

Feedwater and Blowoff Calculations

By V. J. CALISE
Liquid Conditioning Corp.

THERE are a number of factors which can control the maximum permissible blowoff from a boiler. These include:

a. Total dissolved solids in incoming makeup and permissible TDS in the boiler water, according to ABMA standards.

b. On high-pressure boilers above 250 psi, particularly where turbines are used, the silica content of the incoming makeup and the maximum permissible silica in the boiler salines to avoid silica deposits on low-pressure side of turbine blades.

c. Maximum amount of heat from blowoff which can be utilized efficiently in the boiler plant.

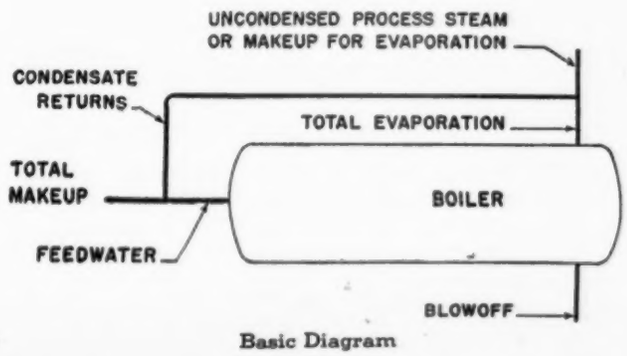
The American Boiler Manufacturers Association standards for maximum permissible total dissolved solids in boiler water for various pressures are:

Boiler Pressure, Psi	Total Dissolved Solids, Ppm
0–300	3500
301–450	3000
451–600	2500
601–750	2000
751–900	1500
901–1000	1250
1001–1500	1000

With high-pressure boilers, it has been found that silica volatilizes off with the steam (the SiO_2 in the steam may be one per cent of the SiO_2 in the boiler salines) and then plates out on the low-pressure turbine blades. In order to avoid this problem it is important to reduce the SiO_2 concentration in the makeup and control the SiO_2 concentration in the boiler salines with proper blowoff.

For high-pressure boilers, particularly where turbines are used with condensers for very low-pressure steam discharge, the maximum permissible silica concentration in the boiler water is usually set by the power engineer or consultant so that there will be no danger of turbine blade silica deposits. Suggested limits sometimes recommended by experts such as Professor Straub of the University of Illinois and by Sheppard T. Powell, consulting engineer, for various pressure boilers operating with condensing turbines are:

Boiler and Turbine Operating Pressure	Max. Silica in Salines, Ppm as SiO_2
250–600 psi	40–50
601–900 psi	20–30
901–1200	10–20
> 1200	< 10



Basic Diagram

These values are not fixed and are subject to change from time to time, based on operating experiences in the field and new experimental data.

There are many methods by which heat available from blowoff can be utilized in the heat cycle However, for any given plant there is a top limit to the amount of such heat which can be effectively utilized, and beyond this limit, any excessive blowoff would mean a considerable loss. The blowoff that can be efficiently used in the plant cycle usually is discharged at about 20 deg F higher than the incoming water so that the loss would be 20 Btu per lb of blowoff discharged to the sewer. Accordingly, it is important to determine the maximum amount of blowoff which can be discharged from a boiler and used efficiently in the plant before fixing the type of treatment and incoming solids and silica concentration. Usually the blowoff is less than five per cent of the maximum total steam evaporation load.

Boiler Blowoff Calculations

When estimating a boiler feedwater treatment plant it is necessary to know the total steam evaporation load and the condensate returns, in per cent of the total steam evaporation load. From these data the makeup for evaporation, the blowoff and finally, the total makeup are computed.

The step-by-step derivation of formula for boiler blowoff, referring to the accompanying sketch, is as follows:

(1) Feedwater = Total evaporation + blowoff
(2) Feedwater = Total makeup + condensate returns
(3) Total makeup = Uncondensed process steam + blowoff
(4) Uncondensed process steam = Makeup for evaporation
(5) Total makeup = Makeup for evaporation + blowoff

Usually the condensate returns have very low or negligible total dissolved solids content. Also, with a given total evaporation load, the condensate returns are constant. From a material balance, we can say,

(6) (Makeup solids) (Total makeup) = (Blowoff solids) (Blowoff)

where Blowoff solids = Maximum allowable total dissolved solids content for boiler pressure according to ABMA

(7) But Total makeup = Makeup for evaporation + Blowoff

where Makeup for evaporation = Uncondensed process steam, and substituting equation (7) in equation (6)

(8) (Makeup solids) (Makeup for evaporation + Blowoff) = (Blowoff solids)(Blowoff),

or

(Makeup solids) (Makeup for evaporation) + (Makeup solids)(Blowoff) = (Blowoff solids) (Blowoff)

(9) and (Makeup solids)(Makeup for evaporation) = (Blowoff)(Blowoff solids − Makeup solids)

$$(10)\ \text{and Blowoff} = \frac{\text{Makeup solids}}{(\text{Blowoff solids} - \text{Makeup solids})} \times (\text{Makeup for evaporation})$$

or substituting Max. allowable boiler TDS for Blowoff solids

$$(10a)\ \text{Blowoff} = \frac{\text{Makeup solids}}{(\text{Max. allowable boiler TDS} - \text{Makeup solids})} \times (\text{Makeup for evaporation})$$

Also from equation (6)

$$(11)\ \text{Blowoff} = \frac{\text{Makeup solids}}{\text{Blowoff solids}} \times \text{Total makeup}$$

$$(11a)\ \text{or Blowoff} = \frac{\text{Makeup solids}}{\text{Max. allowable TDS}} \times \text{Total makeup}$$

Formulas 10 or 10a are used in boiler blowoff calculations.

Example 1

Boiler pressure = 475 psi
Total evaporation = 100,000 lb per hr
Makeup solids = 250 ppm
Blowoff solids = Max. allowable boiler TDS = 2500 ppm according to ABMA
Condensate returns = 50 per cent of total evaporation, or 50,000 lb per hr
Makeup for evaporation = 50,000 lb per hr

From formula 10

$$\text{Blowoff} = \frac{250}{2500 - 250} \times 50{,}000 \text{ lb per hr}$$
$$= 5550 \text{ lb per hr}$$

Total makeup = Makeup for evaporation + blowoff
= 50,000 + 5550
= 55,550 lb per hr

Feedwater = Condensate returns + total makeup
= 50,000 lb per hr + 55,550 lb per hr
= 105,550 lb per hr

Formula 10 can be rewritten as follows in order to determine blowoff based on maintaining a given maximum silica concentration in the boiler with a given incoming silica concentration in the makeup:

$$(12)\ \text{Blowoff} = \frac{\text{Makeup silica}}{(\text{Blowoff silica} - \text{Makeup silica})} \times (\text{Makeup for evaporation})$$

or substituting Max. allowable silica in Boiler salines for Blowoff silica

$$(12a)\ \text{then Blowoff} = \frac{\text{Makeup silica}}{(\text{Max. allowable silica} - \text{Makeup silica})} \times (\text{Makeup for evaporation})$$

Example 2

Boiler pressure = 475 psi
Total evaporation = 100,000 lb per hr
Silica in makeup = 2 ppm (say from hot-process unit)
Blowoff silica = Max. allowable silica concentration in boiler salines = 40 ppm
Condensate returns = 50,000 lb per hr
Makeup for evaporation = 50,000 lb per hr

Then from formula (12)

$$\text{Blowoff} = \frac{2}{40 - 2} \times 50{,}000$$
$$= 2700 \text{ lb per hr}$$

Effect of Limit on Maximum Blowoff in Plant

As stated previously, in many plants the maximum blowoff is fixed by the amount of heat which can be utilized efficiently in the heat cycle. In the following table, taken from a paper on "Silica Removal by an Improved Ion Exchange Process," the effect of limiting the blowoff in two boiler plants to two different limits is shown in its influence on the maximum permissible concentration of silica in the treated makeup. (In this table it is assumed that the TDS in the incoming treated makeup are so low that the blowoff will not be controlled by TDS but by silica.)

TABLE 1

	Plant	A	B
1.	Total evaporation, lb per hr	100,000	100,000
2.	Condensate returns, lb per hr	30,000	30,000
3.	Condensate returns, per cent (*a*)	30	30
4.	Makeup for evaporation, lb per hr	70,000	70,000
5.	Makeup for evaporation, per cent (*b*)	70	70
6.	Blowoff, lb per hr	4,000	10,000
7.	Blowoff, per cent (*c*)	5.7	14.2
8.	Total makeup (including blowoff) lb per hr	74,000	80,000
9.	Maximum permissible SiO_2 in makeup, ppm	0.6	1.4
10.	Number of times makeup concentrates (*d*)	17	7

(*a*) Per cent condensate = $\frac{\text{Condensate, lb per hr}}{\text{Total evaporation, lb per hr}} \times 100$

(*b*) Per cent makeup for evaporation = $\frac{\text{Makeup for evaporation, lb per hr}}{\text{Total evaporation, lb per hr}} \times 100$

(*c*) Per cent blowoff = $\frac{\text{Blowoff, lb per hr}}{\text{Makeup for evaporation, lb per hr}} \times 100$

(*d*) Number of concentrations = $\frac{\text{ppm } SiO_2 \text{ in boiler salines}}{\text{ppm } SiO_2 \text{ in makeup}}$

From this table it can be seen that the higher the amount of blowoff which can be utilized in the plant heat cycle, the higher the silica concentration in the incoming treated makeup can be.

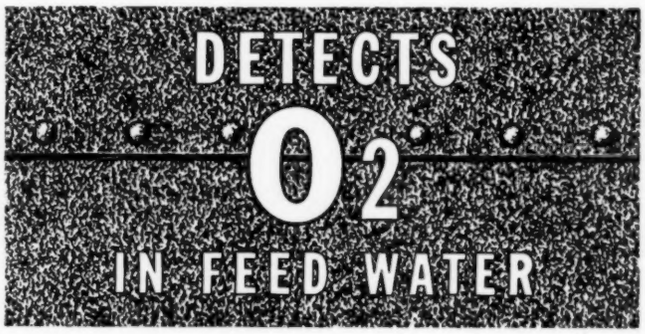
Summary

For any given boiler plant, once the total evaporation condensate returns and makeup for evaporation are known, the blowoff can be calculated, based on maximum total dissolved solids content or on maximum silica content in the boiler salines, after the makeup is treated in the boiler feedwater treating plant. For such blowoff calculations, formula (10) or (10a) can be used to determine the blowoff based on maintaining a given total dissolved solids content in the boiler salines with a given TDS in the makeup as follows:

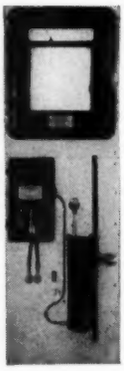
$$(10a)\ \text{Blowoff} = \frac{\text{Makeup solids}}{\text{Max. allowable boiler TDS} - \text{Makeup solids}} \times (\text{Makeup for evaporation})$$

For determining the blowoff based on maintaining a given silica concentration in the boiler salines with a given silica concentration in the treated makeup, formula 12 or 12a can be used.

$$(12a)\ \text{Blowoff} = \frac{\text{Makeup silica}}{(\text{Max. allowable silica} - \text{Makeup silica})} \times (\text{Makeup for evaporation})$$



Oxygen, one very active source of destructive corrosion, is continuously detected and recorded by the Cambridge Dissolved Oxygen Analyzer. The oxygen dissolved in the feed water is determined directly. The oxygen set free by dissociation in the boiler is determined by measuring the free hydrogen in the steam. Cambridge Analyzers are available in models for recording O_2, or O_2 and H_2 simultaneously.



Send for literature

CAMBRIDGE
DISSOLVED OXYGEN
ANALYZERS

CAMBRIDGE INSTRUMENT CO., INC.
3769 Grand Central Terminal New York 17, N. Y.
Pioneer Manufacturers of
PRECISION INSTRUMENTS

Coal Facts

With pending contract negotiations between the bituminous coal operators and John L. Lewis attracting wide public interest, Bituminous Coal Institute has made available certain data which should assist toward a better understanding of the situation. These are of particular interest to the power field and are in part as follows:

1. For every ton of iron or steel produced, 1½ tons of coal go into a blast furnace; and in a normal year about 40 per cent of the jobs in this country are directly or indirectly dependent upon industries that use iron and steel as a major raw material.

2. The coal strike last spring cost the production of 215,000 automobiles and trucks and caused twenty-three railroads to lay off 47,000 employees; this was in addition to 400,000 miners made idle, as well as other thousands in dependent industries. Altogether, the six post-war coal strikes cost the country more than ten million tons of steel production.

3. The steel mills, aside from curtailed production, used up the bulk of their coal reserves during the coal stoppage in March and April, and stand little chance of rebuilding their stockpiles to anywhere near normal if a coal stoppage occurs this summer.

4. Today over 90 per cent of all the bituminous coal mined underground in this country is mechanically cut and 60 per cent is mechanically loaded. Only about 5 per cent is still mined entirely by pick and shovel.

5. The overall fatality rate in coal mines has steadily declined from approximately six deaths per million tons of coal produced in 1911 to 1.72 last year. In other words, the 1947 record was the second lowest in the history of the industry.

6. The average weekly earnings for miners during the month of January 1948 was $75.78 which is the highest recorded by the U. S. Bureau of Labor Statistics for any mass group of workers. This average includes earnings of those who may work only part of the week, due to car shortages, absenteeism and other causes and whose earnings are thus considerably below the average. On the other hand, some earn from $100 to $125 a week.

7. Coal miners are, in general, covered by state unemployment insurance and workmen's compensation and more than 65 per cent of the bituminous coal miners and their families are covered by prepaid medical care, or hospital insurance, or both. They, of course, like workers in other industries, come under the retirement benefits of Federal Social Security.

8. Under the existing wage contract a royalty tax of ten cents per ton, which is passed on to the consumer, goes into the miners' welfare fund. It amounts to 4 million dollars per month.

9. The Lewis-Bridges settlement was for a retirement pension of $100 per month (independent of Social Security) at the age of 62, after 20 years' service. There is some question whether the present welfare fund could sustain this. The legal questions involved have been submitted to the courts for judicial review.

10. In view of the foregoing facts, Bituminous Coal Institute expresses the opinion that "there is no valid reason why the representatives of operators and of the miners could not sit down and discuss their problems temperately and reasonably while the miners are producing coal and earning wages; and the country would not then be subjected to the stresses and losses accompanying each cessation at the mines."

Synthetic Liquid Fuels Plant Dedicated

The synthetic liquid fuels pilot plant and laboratories of the Bureau of Mines at Bruceton, Pa., 13 miles south of Pittsburgh, was dedicated on May 21 with appropriate ceremonies at which Secretary of Interior Krug was the principal speaker.

This 3½-million dollar project was authorized by Congress under the Liquid Fuels Act and has for its purpose the conversion of coal to oil by the gas synthesis, or indirect, Fischer-Tropsch process and the direct hydrogenation Bergius process. *Although coal is employed as the raw* material in both processes, the liquid products to which each is best adapted to produce, differ.

Prior to the dedication ceremonies, the laboratories and plant were open for general inspection.

Steel for Gas Pipe Lines

The Federal Power Commission, together with eight state regulatory commissions in the Middle West and Appalachian area, have called upon the Steel Advisory Council to take steps to assure an adequate supply of steel for natural-gas pipe lines. This would be under the voluntary steel allocation program.

It was pointed out that during the past winter emergency curtailments and allocations of natural gas supply were required in eight states served by one of the larger pipe-line companies, as well as similar curtailments in areas served by other natural-gas systems.

Citations for Pulverized Coal Development

A fitting climax to the pulverized coal anniversary symposium, which highlighted the recent Semi-Annual Meeting of the A.S.M.E. in Milwaukee, were the Citation Awards made at the banquet on June 4 by the University of Wisconsin for pioneer work and subsequent development in pulverized coal firing. The recipients were ***Fred L. Dornbrook,*** *chief engineer of power* plants of the Wisconsin Electric Power Company; **M. K. Drewry,** assistant chief engineer of power plants; **George C. Post,**

One Man at One Point
. . . Controls All!
With Beaumont Birch Coal Handling Equipment, one operator controls all coal handling with finger-tip controls, like this—
Coal arrives by rail, is dumped into hopper, raised by bucket elevator and discharged either into bunker for immediate use or down a chute to yard storage. If it goes to storage, the Beaumont Drag Scraper spreads it into safe, compact layers—eliminating air pockets.
Use any available space. Tail-blocks can be slung between posts and moved by hand—and mechanically moved on I-beam track, by tail-block car, or suspended from an aerial bridle system. The scraper and cable system is operated by one man through remote control. One company, Beaumont Birch, supplies all necessary equipment.
Complete engineering service available by writing right now to—
BEAUMONT BIRCH COMPANY
1506 RACE STREET • PHILADELPHIA, PA.
Designers Manufacturers Erectors
BULK MATERIAL HANDLING SYSTEM

TWO RACKS + TWO PINIONS = square closing!

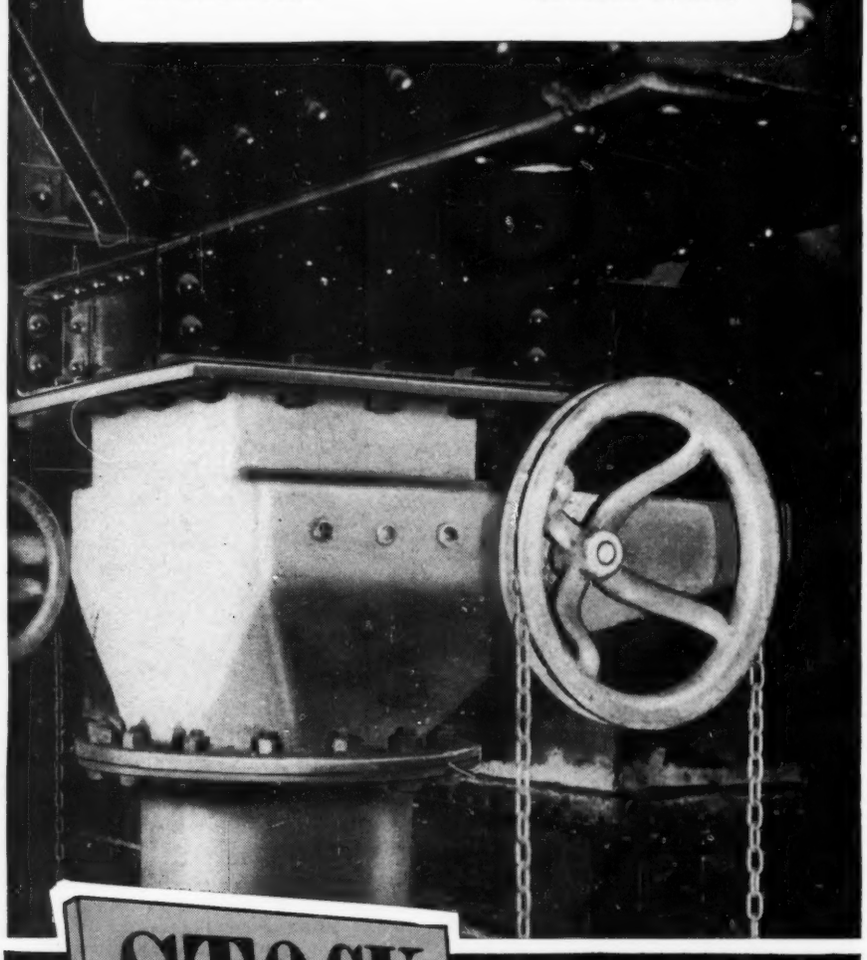
The twin rack and pinion design of S. E. Co. Coal Valves is a guarantee that these valves will operate easily and dependably. Fine coal particles and moisture can't harm working parts in the S. E. Co. Coal Valve . . . can't cause sticking or hard operation because all working mechanism is shielded.

Write for illustrated bulletin

Address

STOCK ENGINEERING COMPANY

713 HANNA BLDG. CLEVELAND 15, OHIO



STOCK ENGINEERING CO.

★ CONICAL Non-Segregating Coal Distributors ★ S.E.CO. Coal Valves and Coal Scales

retired vice president in charge of power; and **Gould W. Van Derzee,** president of the Company.

Elected C.E. Vice President

George D. Ellis for some years past controller of Combustion Engineering Company, Inc., New York, has been elected vice president in addition to his duties as controller. A graduate of St. Louis University, he joined Heine Boiler Company of St. Louis in 1915 and when that company was acquired by Combustion Engineering in 1928, he was brought to New York in the capacity of cost accountant.

Simultaneous announcement was made on May 3 of the appointment of **Irving B. Swigart** as secretary of the company in addition to assistant treasurer, which position he has held since 1939. Mr. Swigart came with Combustion Engineering Company at the time of its acquisition of Green Engineering Company of East Chicago and was brought to the New York headquarters in 1929 as a cost accountant, being advanced to assistant secretary in 1938.

New E.E.I. Officers

At the Atlantic City Annual Convention of the Edison Electric Institute, June 1–3, **Ernest R. Acker** of the Central Hudson Gas & Electric Company was elected president for the ensuing year. He succeeds **C. E. Oakes** of Allentown, Pa. **Elmer L. Lindseth,** president of the Cleveland Electric Illuminating Company, was elected vice president. Other officers re-elected were **Col. H. S. Bennion,** vice president and managing director; **K. N. Crumb,** treasurer, and **Mae B. Woods,** secretary.

Obituary

Rudolf M. Ostermann, formerly vice president of The Superheater Company, at Chicago, died at his home in Evanston, Ill., on May 4. Born in Germany and graduated from the University of Charlottenberg in 1900, in electrical and mechanical engineering, he became associated with the German branch of General Electric Company and in 1902 came to Schenectady. At various times he represented that company in South America and in 1911 joined The Superheater Company of which he was elected vice president in 1915 with headquarters in Chicago. He retired in November 1946.

James A. Powell, chief mechanical engineer of Stone & Webster Engineering Corporation, died at the Copley Plaza Hotel, Boston, on June 9th. He had been with that company since 1941 after being identified for a number of years with Gilbert Associates of Reading, Pa. He was a member of the A.S.M.E., the A.I.E.E. and the National Society of Professional Engineers.

REVIEW OF NEW BOOKS

Any of the books here reviewed may be secured through Combustion Publishing Company, Inc., 200 Madison Ave., N. Y.

Steam, Air and Gas Power Fourth Edition

By W. H. Severns and H. E. Degler

This is primarily a textbook for students in heat-power engineering courses, with a number of selected problems following each chapter. The treatment follows the usual sequence with introductory chapters on heat and heat power plants, followed by the principles of thermodynamics and discussions of fuels, steam generation, water conditioning, draft, prime movers, compressed air, internal-combustion engines, etc. Much of the text of the previous edition has been revised and some illustrations replaced. New material on the gas turbine has been added.

The book contains 509 pages, cloth bound and is priced at $4.75.

Locations of Principal Electric Utility Stations

The Federal Power Commission has issued a revision of its previous publication showing the principal electric utility generating stations and transmission lines in the United States. Comprising eleven regional maps and six supplementary sheets, the series shows, in general, transmission lines of 22 kv and above, electric utility generating stations of 1000 kw and above and industrial electric generating stations of 1000 kw and above when interconnected with an electric utility.

The eleven regions shown in the series are the New England, Middle Atlantic, Southeastern, East Central, Upper Great Lakes, Ozark and Panhandle, Western Gulf, Southwest Mountain, Northwest Central, Pacific Northwest and Pacific Southwest. The six supplementary sheets show details of the following congested areas: Boston, New York and Philadelphia, New Jersey, Rhode Island and cities in the Southeastern and Pacific Southwest areas.

Accompanying the maps series is a plant and ownership list giving plant name, type, capacity, location by state and operating utility class of ownership. Each operating utility and generating station listed in the index has been assigned a key number to facilitate its identification on the map. The listing identifies each class of ownership according to whether it is a privately owned utility, an industrial establishment incidentally furnishing electric service, a publicly owned utility, or a mutually owned or cooperative utility.

The maps are sold exclusively by the Federal Power Commission, Washington, D. C. The complete set of eleven with supplementary sheets is $2.50, and individual maps are 25¢ each.

Fan Engineering Fifth Edition

This well-known handbook, published by Buffalo Forge Company under the editorship of Richard D. Madison, was last issued in 1938. Since then much has transpired in the line of air engineering and fan applications and this revised edition is most timely. The text has been largely rewritten; engineering data have been expanded; and considerable additional information on air conditioning has been included.

Part 1 of the text is devoted to the "physics of air," under which are treated properties of air and air-vapor mixtures, heat transmission, fluid flow and air distribution. Part 2 deals with fans of various types, the laws of fan performance, fan testing, fan systems, sound, fan dynamics, drives and the jet pump. Part 3 covers a wide range of fan applications, and Part 4 the details of fans and related equipment as well as air conditioning. Between each chapter is a comprehensive bibliography.

Bound in flexible leather with over 800 pages, $4^1/_4 \times 6^1/_2$ in., the handbook not only is replete with tables, curves and charts but also contains many diagrams and other illustrations. It is priced at $6.

A.S.T.M. Specifications for Steel Piping

This compilation, issued by the American Society for Testing Materials, under date of March 1948, gives in the latest form all of the specifications covering steel piping materials—pipe, tubes, castings, bolting, etc.

There are widely used specifications covering pipe for service at normal and elevated temperatures and several carry '47 designations indicating that these were revised, effective last year. In the field of tubing for boilers and superheaters there are 13 specifications covering seamless, welded and other types of tubes involving a wide range of chemical composition and properties. There are three specifications each for still tubes and for heat-exchanger and condenser tubes. Five relate to castings for general application and high-temperature service. Three standards pertain to forgings or rolled pipe flanges and one covers welded fittings. There are three relating to bolting, and the book is made complete by the inclusion of the classification of grain size in steel, E-19, with its two charts.

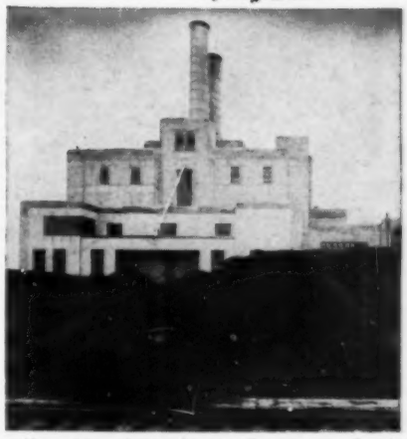
The book contains 315 pages with heavy paper cover, and is priced at $3.

STOCKPILING AND RECLAIMING COAL

only a 1-Man JOB WITH A SAUERMAN POWER SCRAPER

It takes only *one man*, easily trained for the job, to operate a Sauerman Scraper machine, yet it can greatly increase your operating efficiency in storing and reclaiming coal.

For only a few cents per ton, all of your stockpile handling can be done cleanly with a Sauerman Scraper that builds compact, homogeneous piles, free from segregation, and safer from combustion hazards, with better utilization of space on any available area. Installation cost is surprisingly small. Let our Engineering Department study your coal handling problems and advise on correct equipment for your needs. Catalog on request.



Above picture shows a Sauerman Scraper, powered with 60 h.p. electric motor, reclaiming coal from a 30,000 ton stockpile which the scraper has previously built on ground space between a power plant and railway embankment. From a station overlooking storage area, the operator controls every move of the scraper with automatic controls

SAUERMAN BROS., Inc.

550 S. CLINTON ST., CHICAGO 7, ILL.

EYES ON TOMORROW..

...for the complex *flow control needs* of Modern Industry

Throughout more than a hundred years of making valves, The Wm. Powell Company has continually had its "eyes on tomorrow"—anticipating the future flow control requirements of industry.

This foresight was responsible for Powell's introduction of the first regrinding globe valve back in 1865. The design on which the patent was granted is shown above.

And because many years ago Powell foresaw the vast development that was to come in the field of power, the Powell Engineering staff started to develop a complete line of valves especially adapted for power plants.

Today there's a Powell Bronze, Iron, or Steel Valve specifically designed to meet every flow control requirement of the modern power services.

Furthermore, because power shut-downs can be very costly, Powell Valves for Power Plants are designed especially for long, dependable service with maintenance reduced to a minimum.

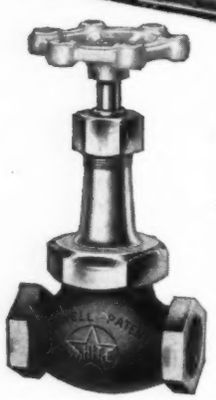


Fig. 1708 — 200-pound Bronze Globe Valve with screwed ends, union bonnet, renewable specially heat treated stainless steel seat and regrindable, renewable "Powellium" wear-resisting nickel-bronze disc.

Fig. 559—125-pound Iron Body Bronze Mounted Swing Check Valve with flanged ends, bolted flanged cap and regrindable, renewable bronze seat and disc.

Fig. 375 — 200-pound Bronze Gate Valve. Screwed ends, union bonnet, inside screw rising stem and renewable "Powellium" wear-resisting nickel-bronze disc.

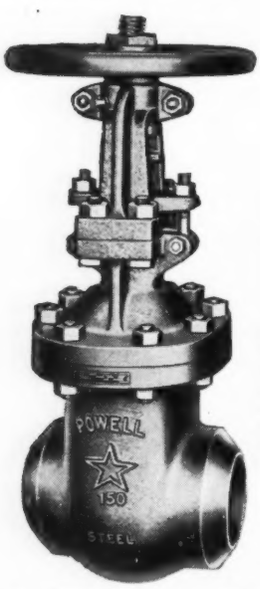


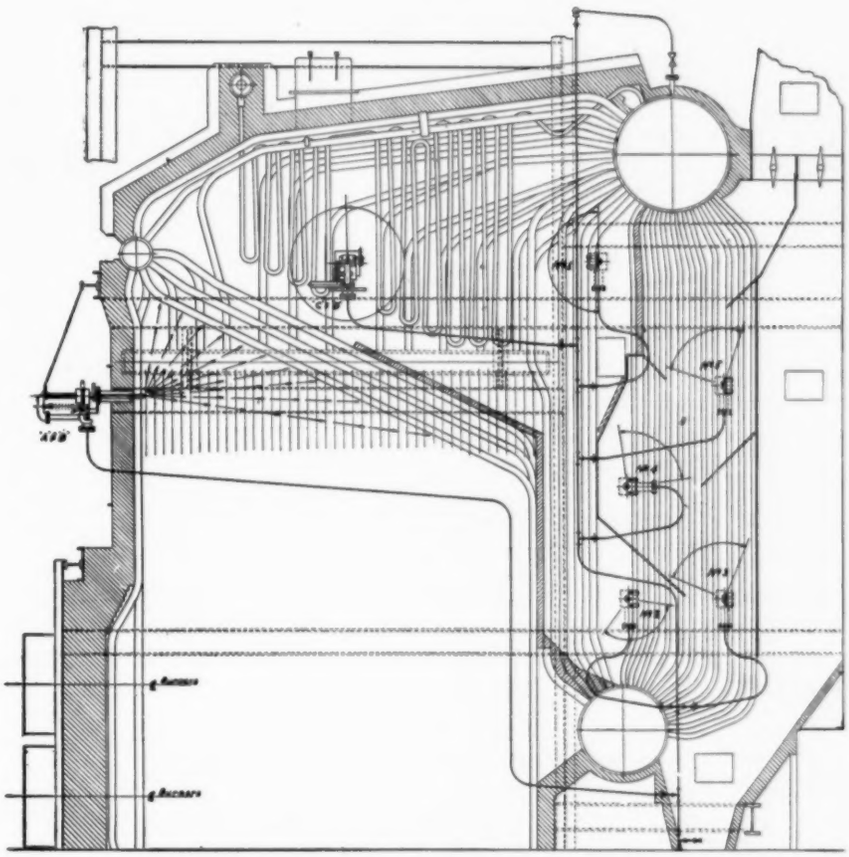
Fig. 1503 W. E. — Class 150-pound Cast Steel Gate Valve with welding ends, outside screw rising stem, bolted flanged yoke and tapered solid wedge.

Fig. 241—Large 125-pound Iron Body Bronze Mounted Globe Valve. Made in sizes 2" to 16", inclusive. Has outside screw rising stem, bolted flanged yoke and regrindable, renewable bronze seat and disc.

The Wm. Powell Company
Cincinnati 22, Ohio
DISTRIBUTORS AND STOCKS IN ALL PRINCIPAL CITIES

POWELL VALVES

CLEAN HEATING SURFACE and LOW MAINTENANCE



460 p.s.i. PULVERIZED COAL FIRED BENT TUBE BOILER

- The high temperature zone, first pass screen tubes are cleaned by BAYER RETRACTABLE GUN TYPE MASS-FLOW CLEANERS located in the front furnace wall. When not in use the nozzle is retracted from the furnace, where it is away from the heat, thus assuring long and efficient service life.

- The superheater is cleaned by BAYER LONG RETRACTABLE MULTI-NOZZLE CLEANERS. The elements are advanced for cleaning and after the cleaning cycle are entirely withdrawn from the furnace. By the use of such Retractable Cleaners heating surface is kept clean at all times, and element maintenance is negligible.

- The rear banks of boiler tubes are cleaned by BAYER conventional revolving elements.

The soot cleaner system illustrated emphasizes the fact that the soot blower in every case should be engineered to suit the operating conditions of the boiler to which it is applied.

BAYER engineering is at your service at any time. We will gladly co-operate with you in order that the best equipment may be correctly applied to efficient cleaning of heating surface under the operating conditions in your plant.

Over the years a large Mid-West Utility Company has used BAYER SOOT BLOWERS. The first installation was made over twenty years ago. Eleven repeat orders for BAYER SOOT BLOWERS to equip new boiler installations have been ordered. The boiler illustrated at the left was installed last year. The record of efficiency, dependability and service demonstrated by BAYER EQUIPMENT in past years resulted in BAYER being selected for the new boiler.

The Bayer Company

ST. LOUIS, MISSOURI, U.S.A.

FOR HIGHEST FIRST AND FINAL VALUE BUY BAYER

Are Power Plant Coal Bills Too High?

In many cases, steam generating costs are too high because coal purchases are limited to a narrow range of costly premium coals—with little or no possibility of purchasing the best coal value available in a changing or competitive market.

Modern power plant design has advanced to the point where complete fuel flexibility is entirely possible. The cost to provide fuel flexibility in new plants, or when modernizing existing plants, is but a small part of the capital investment. Yet this small additional investment pays dividends throughout the life of the plant by providing *reliable utilization* of various coals—enabling the operator to purchase the best fuel value under all market conditions.

The Engineering Research Department of the Ohio Coal Association welcomes the opportunity to supply helpful information to power plant designers, owners, and operators on how power plants, large and small, can widen coal selection and reduce coal bills. Inquiries are invited.

THIS BOOKLET contains charts, illustrations, diagrams, and technical data on • fuel flexibility and power costs • how to conduct a fuel investigation for lower power costs • how burning equipment affects fuel performance — and other helpful information of interest to power plant designers, owners and operators. Free on request—write today.

OHIO COAL ASSOCIATION Engineering Research

OHIO COAL ASSOCIATION

ROCKEFELLER BUILDING • CLEVELAND 13, OHIO

General and Classified Index

COMBUSTION, Volume Nineteen, July 1947 Through June 1948

EDITORIALS—

		Page
A Consumer Dilemma	Aug. 1947	27
Annual Fuel Rate per Kilowatt-Hour, The	Mar. 1948	29
Coal Reserves	Mar. 1948	29
Colloidal Fuel	Feb. 1948	31
Combustion Engineering Courses	Jan. 1948	25
Electric Utility Growth	Nov. 1947	29
Engineer in Civic Affairs, The	Apr. 1948	31
Financing Utility Expansion	June 1948	31
Free Enterprise System, The	July 1947	21
Fuel Economy Conference, The	Oct. 1947	29
Future Need for Engineers, The	Sept. 1947	29
Future of Coal, The	Dec. 1947	31
High Construction Costs Favor Semi-Outdoor Stations	Sept. 1947	29
Industry Again Penalized	Apr. 1948	31
Lewis Wins Again	July 1947	21
Meeting Increasing Power Demand	Aug. 1947	27
Omission of I. D. Fans	Mar. 1948	29
Opportunities for Engineering Graduates in the Power Field	May 1948	27
Overlooked Factors in Atmospheric Pollution	Nov. 1947	29
Power on the Pacific Coast	May 1948	27
Pulverized Coal Anniversary	May 1948	27
St. Lawrence Power Up for Congressional Action	Feb. 1948	31
Scrap Scarcity	Dec. 1947	31
Smoke in New York	June 1948	31
Steam Generator Progress and Trends	Jan. 1948	25
Synthetic Oil Receiving Wide Attention	Oct. 1947	29

ARTICLES—

		Page
A.S.M.E. Meets at Atlantic City—*Sub-Saturation Reheat Cycle; The New Sporn Station; Heating Value of Fuels; Furnaces for By-Product Fuels; Nuclear Energy; Synthetic Liquid Fuels; Forced Circulation Boiling of Water; Flash Drying; Customer-Manufacturer Relations; Burning Pulverized Coal Under Pressure; Expanded Tube Joints; President's Address*	Dec. 1947	37
A.S.M.E. Semi-Annual Meeting at Chicago—*President's Address; Central Station Design; Industrial Steam Plant Design; Furnace Performance Factors; Sulphate-Type Deposits on Boiler Tubes; Quick Starting of Turbines; Boiler Drum Steel After Forty Years' Service; Gas Turbines; Coal and Ash Handling; New Process for Producing Char; Atomic Power*	July 1947	22
An Appraisal of the Fuel Situation, *Midwest Power Conference.* By John Van Brunt	Apr. 1948	36
An Appraisal of the Gas Turbine for Power Plants. By A. G. Christie	Nov. 1947	41
Application of Heat Balance Analysis to Industrial Plants, *Midwest Power Conference.* By H. C. Carroll	Apr. 1948	37
Atomic Energy and American Industry. By David E. Lilienthal	Nov. 1947	34
Atomic Energy and The Engineer, *A.S.M.E. Annual Meeting.* by David E. Lilienthal	Dec. 1947	42
Atomic Power, *A.S.M.E. Semi-Annual Meeting at Chicago.* By B. R. Prentice and A. O. Nier	July 1947	31
Bark Burning Methods. By J. H. Freiday	Oct. 1947	45
Behavior of Ash in Pulverized-Coal-Fired Furnaces. By P. Cohen and R. C. Corey	Jan. 1948	33
Boiler Drum Steel After Forty Years' Service, *A.S.M.E. Semi-Annual Meeting at Chicago.* By H. S. Blumberg and G. V. Smith	July 1947	27
Boiler Water Treatment, *Midwest Power Conference.* By Dr. R. C. Ulmer	Apr. 1948	38
Burning Bagasse at Cuban Sugar Centrals. By H. G. Meissner	Jan. 1948	26
Burning Brown Coal on Stokers. By I. M. Stewart, J. R. Nicholson and H. P. Reinbach	Nov. 1947	47
Causes and Prevention of Condensate Return-Line Corrosion, *Midwest Power Conference.* By R. T. Hanlon	Apr. 1948	39
Central Station Design, *A.S.M.E. Semi-Annual Meeting at Chicago.* By E. H. Krieg	July 1947	22
Coal and Ash Handling, *A.S.M.E. Semi-Annual Meeting at Chicago.* By R. L. Hearn, R. F. Legget and G. A. Gaffert	July 1947	30
Coal Facts	June 1948	53
Combined Steam and Electric Supply in New York. By W. F. Davidson and M. J. Steinberg	Sept. 1947	30
Construction Cost Trends and Implications. By Wm. F. Ryan	July 1947	33
Corrosion as Related to Acid Cleaning	Aug. 1947	35
Corrosion: Its Effect in Boiler Systems. By Robert L. Reed. *Part I*	May 1948	28
Part II	June 1948	43
Court Decisions Affecting Power Plants. By Leo T. Parker	Apr. 1948	47
Customer-Manufacturer Relations, *A.S.M.E. Annual Meeting.* By W. S. Patterson, L. A. Darling, Martin Frisch, D. S. Walker, D. W. R. Morgan, L. M. Goldsmith, L. E. Newman, A. E. Raynor, H. C. Stevenson, J. Campbell, Jr., C. B. Campbell, W. H. Rowand, Ollison Craig, S. B. Roberts, W. T. Sherman, G. E. Anderson, R. F. Hanson, J. W. Anne, A. L. Glaeser, L. D. Whitescarver, Stephen Bencze, Paul Diserens and L. V. Armstrong	Dec. 1947	39
Developments in Burning Pulverized Coal	June 1948	32
Early American Wooden Boilers. By C. G. R. Humphreys	Nov. 1947	38
Energy Sources and Output by Electric Utilities	Mar. 1948	43
Engineers Discuss How to Keep Power Boilers in Uninterrupted Service	Feb. 1948	43
Expanded Tube Joints, *A.S.M.E. Annual Meeting.* By G. Sachs	Dec. 1944	43
Experiences with Multiple Fuel Firing, *Midwest Power Conference.* By F. H. Hollis	Apr. 1948	36
Experimental Combustion of Pulverized Coal at Atmospheric and Elevated Pressures, *A.S.M.E. Annual Meeting.* By Herbert R. Hazard and Fred D. Buckley	Dec. 1947	41
Factors in Selection of Steam Generating Units. By W. S. Patterson	Mar. 1948	35
Federal Power Commission Urges Further Interconnection	Dec. 1947	49
Feedwater and Blowoff Calculations. By V. J. Calise	June 1948	51
Five Years Performance of Minnesota Paper Mill Steam Generating Unit. By A. S. Oliver	Aug. 1947	28
Flash Drying of Materials by a New Method, *A.S.M.E. Annual Meeting.* By C. W. Gordon	Dec. 1947	43
Forced Circulation Boiling of Water, *A.S.M.E. Annual Meeting.* By R. C. Martinelli and D. B. Nelson	Dec. 1947	43
Foreign Power Situation, *Midwest Power Conference.* By Walker L. Cisler	Apr. 1948	35
Fuels Meeting Stresses Small Plant Problems and Atmospheric Pollution	Nov. 1947	30
Fuels Performance at Port Washington Station. By W. A. Pollock	June 1948	41
Furnace Design Methods, With and Without Water Walls, *Midwest Power Conference.* By Ollison Craig	Apr. 1948	37
Furnace Performance Factors, *A.S.M.E. Semi-Annual Meeting at Chicago.* By L. B. Schueler, W. T. Reid, R. C. Corey, A. R. Mumford, C. G. R. Humphreys and G. W. Bice	July 1947	24
Furnaces for By-Product Fuels, *A.S.M.E. Annual Meeting.* By Otto de Lorenzi	Dec. 1947	40
Future Electric Power Needs, *Midwest Power Conference.* By F. R. Benedict	Apr. 1948	36
Gas Turbine History. By T. A. Crowe	Mar. 1948	46
Gas Turbines, *A.S.M.E. Semi-Annual Meeting at Chicago.* By Alan Howard, J. I. Yellott, C. F. Kottcamp, J. R. Haskins, Jr., A. E. Hershey and J. H. Potter	July 1947	28
Gas Turbine Test, *Midwest Power Conference.* By T. J. Putz	Apr. 1948	40
Generating Station Auxiliaries. By W. Szwander	Oct. 1947	41
Heating Value of Fuels, *A.S.M.E Annual Meeting.* By E. F. Fiock, R. S. Jessup, F. W. Fuegg, A. G. Christie and R. V. Kleinschmidt	Dec. 1947	38
High Alkalinity and Organic Materials for Sludge Removal, *Midwest Power Conference.* By Selden K. Adkins	Apr. 1948	38
Hot-Process Conditioned Water for High-Pressure Boilers. By A. C. Dresher	Jan. 1948	31
Illinois Power Company's New Havana Power Station. By H. E. Steinhoff	Dec. 1947	32
Industrial Steam Plant Design, *A.S.M.E. Semi-Annual Meeting at Chicago.* By B. A. Lininger	July 1947	23
Industrial Turbine Maintenance. By G. W. Anderson	May 1948	43
Influences on Slag Behavior. By Dr. F. O. A. Münzinger	Mar. 1948	32
Instruments and Combustion Control for Small Plants. By W. H. Pugsley	Jan. 1948	41
Iron in Feedwater, *Midwest Power Conference.* By F. G. Straub	Apr. 1948	39
Is Reheat Coming Back?	Sept. 1947	33

PAGE

Japanese Electric Power System, *Midwest Power Conference.* By E. J. Burger....Apr. 1948 39
Keystone Steel & Wire Co. Adds to Boiler Capacity. by Walter Gaumer and M. O. Funk....Feb. 1948 32
Large Generating Unit Goes Into Service at Chicago...Oct. 1947 38
Lessons from the Tests and Present Status of the Art, *Part I.* By B. J. Cross....June 1948 36
Part II. By E. M. Powell....June 1948 39
Mechanism of Combustion of Pulverized Coal. By A. A. Orning....Sept. 1947 41
Midwest Power Conference—*Future Power Needs; Foreign Power Situation; An Appraisal of the Fuel Situation; The Trek of Industry Westward; Application of Heat Balance to Industrial Plants; Furnace Design; Boiler Water Treatment; Experiences with Multiple Fuel Firing; Iron in Feedwater, Causes and Prevention of Condensate Return-Line Corrosion; High Alkalinity and Organic Material for Sludge Removal; Gas Turbine Test; Electric Power in Japan; Power Plant Operator Training*....Apr. 1948 35
Modern Boiler Design Increases Availability. By A. R. Mumford....Feb. 1948 35
New Process for Producing Char, *A.S.M.E. Semi-Annual Meeting at Chicago.* By A. D. Singh and L. J. Kane....July 1947 31
New Sporn Station, The, *A.S.M.E. Annual Meeting.* By Philip Sporn....Dec. 1947 37
Notes on Radiology of Welded Pipe Joints....Jan. 1948 44
Nuclear Engineering—Basic Design Background, *A.S.M.E. Annual Meeting.* By Dr. John R. Huffman.Dec. 1947 42
Pioneer Work at Milwaukee. By F. L. Dornbrook....June 1948 32
Power Conference Reports on the World Fuel Situation.Oct. 1947 30
Power Plant Operator Training, *Midwest Power Conference.* By J. P. Flynn, Garrett Burgess, Kenneth R. Hodges, Stephen C. Casteel and Julius Barbour..Apr. 1948 40
Quick Starting of High-Pressure Steam Turbine Units. By J. C. Falkner, R. S. Williams, and R. H. Hare....Aug. 1947 31
Removal of Silica Deposits from Steam Turbines by Caustic Soda. By I. B. Dick....Dec. 1947 44
Safety Valves for Stationary Power Boilers. By J. R. Kruse....Mar. 1948 30
Selection of Mechanical Draft Fans, The. By A. P. Darlington....May 1948 35
Significance of Condensation Nuclei in Atmospheric Pollution, *Tenth Annual Joint Fuels Conference.* By Hans Neuberger....Nov. 1947 32
Significance of Temperature in Titration of Iodine with Winkler Test for Dissolved Oxygen. By E. T. Pinkney and R. S. Young....Oct. 1947 35
Silica Deposits in Steam Turbines from Softening of Makeup Through Natural Zeolite. By F. R. Owens..July 1947 37
Small Boiler Plant Problems, *Tenth Annual Joint Fuels Conference.* By C. A. Reed, P. F. White, C. F. Golding, H. L. Wagner, H. N. Hermann, W. H. Pugsley, C. E. Miller, H. B. Lammers and J. F. Barkley....Nov. 1947 30
Some Early Water-Tube Boilers. By C. G. R. Humphreys....May 1948 38
Some Notes on Boiler Practice in Germany. By Dr. F. O. A. Münzinger....Aug. 1947 41
Stability of the Atmosphere and Its Influence on Air Pollution, *Tenth Annual Joint Fuels Conference.* By Henry F. Hebley....Nov. 1947 33
Steam-Electric Power in Spain. By Saturnio Alverez..May 1948 33
Steam for Chile's New Steel Plant. By F. C. Senior..Apr. 1948 32
Steam Generation and Gas Turbine Developments in Switzerland. By Dr. H. J. Rose....Sept. 1947 35
Sub-Saturation Reheat Cycle, A. By W. E. Caldwell..Feb. 1948 45
Sulphate-Type Deposits on Boiler Tubes, *A.S.M.E. Semi-Annual Meeting at Chicago.* By J. F. Barkley, L. R. Burdick and A. A. Berk....July 1947 26
Synthetic Fuels Plants Recommended....Feb. 1948 49
Synthetic Liquid Fuels, *A.S.M.E. Annual Meeting.* By Dr. W. C. Schroeder....Dec. 1947 41
Test of a Continuous-Discharge, Spreader-Stoker-Fired Unit. By M. O. Funk....Sept. 1947 37
Thermodynamics of Steam and Gas Turbines Compared. By A. H. Meldahl....Aug. 1947 43
Trek of Industry Westward, The, *Midwest Power Conference.* By John M. Drabelle....Apr. 1948 36
Two Years' Performance of the Chesterfield Power Station. By R. S. Reed....Apr. 1948 43
Underground Coal Gasification, *Tenth Annual Joint Fuels Conference.* By Dr. W. C. Schroeder and H. Fies....Nov. 1947 33
Work of Fuel Research Station in Study of Boiler Deposits....Aug. 1947 37
World-Wide Oil Demand and Supply. By R. M. Bartlett....May 1948 40
X-Ray Protection Being Studied at Bureau of Standards....July 1947 41

AUTHORS—

PAGE

Adkins, Selden K.—*High Alkalinity and Organic Materials for Sludge Removal,* Midwest Power Conference....Apr. 1948 38
Alverez, Saturnio—*Steam-Electric Power in Spain*....May 1948 33
Anderson, G. W.—*Industrial Turbine Maintenance*....May 1948 43
Barbour, Julius, J. P. Flynn, Garrett Burgess, Kenneth R. Hodges and Stephen C. Casteel—*Power Plant Operator Training,* Midwest Power Conference....Apr. 1948 40
Barkley, J. F., L. R. Burdick and A. A. Berk—*Sulphate-Type Deposits on Boiler Tubes,* A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 26
Barkley, J. F., C. A. Reed, P. F. White, C. F. Golding, H. L. Wagner, H. N. Hermann, W. H. Pugsley, C. E. Miller, and H. B. Lammers—*Small Boiler Plant Problems,* Tenth Annual Joint Fuels Conference....Nov. 1947 30
Bartlett, R. M.—*World-Wide Oil Demand and Supply*...May 1948 40
Benedict, F. R.—*Future Electric Power Needs of the U. S.,* Midwest Power Conference....Apr. 1948 36
Berk, A. A., J. F. Barkley and L. R. Burdick—*Sulphate-Type Deposits on Boiler Tubes,* A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 26
Bice, G. W., L. B. Schueler, W. T. Reid, R. C. Corey, A. R. Mumford and C. G. R. Humphreys—*Furnace Performance Factors,* A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 24
Blumberg, H. S., and G. V. Smith—*Boiler Drum Steel After Forty Years' Service,* A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 27
Buckley, Fred D., and Herbert R. Hazard—*Experimental Combustion of Pulverized Coal at Atmospheric and Elevated Pressures,* A.S.M.E. Annual Meeting....Dec. 1947 41
Burdick, L. R., J. F. Barkley and A. A. Berk—*Sulphate-Type Deposits on Boiler Tubes,* A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 26
Burger, E. J.—*Japanese Electric Power System,* Midwest Power Conference....Apr. 1948 39
Burgess, Garrett, Julius Barbour, J. P. Flynn, Kenneth R. Hodges and Stephen C. Casteel—*Power Plant Operator Training,* Midwest Power Conference....Apr. 1948 40
Caldwell, W. E.—*A Sub-Saturation Reheat Cycle*....Feb. 1948 45
Calise, V. J.—Feedwater and Blowoff Calculations....June 1948 51
Carroll, H. C.—*Application of Heat Balance Analysis to Industrial Plants,* Midwest Power Conference....Apr. 1948 37
Casteel, Stephen C., Garrett Burgess, Julius Barbour, J. P. Flynn and Kenneth R. Hodges—*Power Plant Operator Training,* Midwest Power Conference....Apr. 1948 40
Christie, A. G.—*An Appraisal of the Gas Turbine for Power Plants*....Nov. 1947 41
Christie, A. G., E. F. Fiock, R. S. Jessup, F. W. Fuegg and R. V. Kleinschmidt—*Heating Value of Fuels,* A.S.M.E. Annual Meeting....Dec. 1947 38
Cisler, Walker L.—*Foreign Power Situation,* Midwest Power Conference....Apr. 1948 35
Cohen, P., and R. C. Corey—*Behavior of Ash in Pulverized-Coal-Fired Furnaces*....Jan. 1948 33
Corey, R. C., G. W. Bice, L. B. Schueler, W. T. Reid, A. R. Mumford and C. G. R. Humphreys—*Furnace Performance Factors,* A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 24
Corey, R. C., and P. Cohen—*Behavior of Ash in Pulverized-Coal-Fired Furnaces*....Jan. 1948 33
Craig, Ollison—*Furnace Design Methods, With and Without Water Walls,* Midwest Power Conference....Apr. 1948 37
Cross, B. J.—Lessons from the Tests and Present Status of the Art, Part I....June 1948 36
Crowe, T. A.—*Gas Turbine History*....Mar. 1948 46
Darlington, A. P.—*The Selection of Mechanical Draft Fans*....May 1948 35
Davidson, W. F., and M. J. Steinberg—*Combined Steam and Electric Supply in New York*....Sept. 1947 30
de Lorenzi, Otto—*Furnaces for By-Product Fuels,* A.S.M.E. Annual Meeting....Dec. 1947 40
Dick, I. B.—*Removal of Silica Deposits from Steam Turbines by Caustic Soda*....Dec. 1947 44
Dornbrook, F. L.—Pioneer Work at Milwaukee....June 1948 32
Drabelle, John M.—*The Trek of Industry Westward,* Midwest Power Conference....Apr. 1948 36
Dresher, A. C.—*Hot-Process Conditioned Water for High-Pressure Boilers*....Jan. 1948 31
Falkner, J. C., R. S. Williams and R. H. Hare—*Quick Starting of High-Pressure Steam Turbine Units*....Aug. 1947 31
Fies, H., and W. C. Schroeder—*Underground Coal Gasification,* Tenth Annual Joint Fuels Conference....Nov. 1947 33
Fiock, E. F., R. S. Jessup, F. W. Fuegg, A. G. Christie and R. V. Kleinschmidt—*Heating Value of Fuels,* A.S.M.E. Annual Meeting....Dec. 1947 38
Freiday, J. H.—*Bark Burning Methods*....Oct. 1947 45
Fuegg, F. W., E. F. Fiock, R. S. Jessup, A. G. Christie and R. V. Kleinschmidt—*Heating Value of Fuels,* A.S.M.E. Annual Meeting....Dec. 1947 38
Funk, M. O.—*Test of a Continuous-Discharge, Spreader-Stoker-Fired Unit*....Sept. 1947 37
Funk, M. O., and Walter Gaumer—*Keystone Steel & Wire Co. Adds to Boiler Capacity*....Feb. 1948 32

PAGE

Gaffert, G. A., R. L. Hearn and R. F. Legget—*Coal and Ash Handling*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 30
Gaumer, Walter, and M. O. Funk—*Keystone Steel & Wire Co. Adds to Boiler Capacity*....Feb. 1948 32
Golding, C. F., C. A. Reed, P. F. White, H. S. Wagner, H. N. Hermann, W. H. Pugsley, C. E. Miller, H. B. Lammers and J. F. Barkley—*Small Boiler Plant Problems*, Tenth Annual Joint Fuels Conference....Nov. 1947 30
Gordon, C. W.—*Flash Drying of Materials by a New Method*, A.S.M.E. Annual Meeting....Dec. 1947 43
Hanlon, R. T.—*Causes and Prevention of Condensate Return-Line Corrosion*, Midwest Power Conference..Apr. 1948 39
Hare, R. H., J. C. Falkner and R. S. Williams—*Quick Starting of High-Pressure Steam Turbine Units*....Aug. 1947 31
Haskins, J. R., Jr., Alan Howard, J. I. Yellott, C. F. Kottcamp, A. E. Hershey and J. H. Potter—*Gas Turbines*, A.S.M.E. Semi-Annual Meeting at Chicago..July 1947 28
Hazard, Herbert R., and Fred D. Buckley—*Experimental Combustion of Pulverized Coal at Atmospheric and Elevated Pressures*, A.S.M.E. Annual Meeting..Dec. 1947 41
Hearn, R. L., R. F. Leggett and G. A. Gaffert—*Coal and Ash Handling*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 30
Hebley, Henry F.—*Stability of the Atmosphere and Its Influence on Air Pollution*, Tenth Annual Joint Fuels Conference....Nov. 1947 33
Hermann, H. N., C. A. Reed, P. F. White, C. F. Golding, H. L. Wagner, W. H. Pugsley, C. E. Miller, H. B. Lammers and J. F. Barkley—*Small Boiler Plant Problems*, Tenth Annual Joint Fuels Conference....Nov. 1947 30
Hodges, Kenneth R., J. P. Flynn, Garrett Burgess, Stephen C. Casteel and Julius Barbour—*Power Plant Operator Training*, Midwest Power Conference....Apr. 1948 40
Hollis, F. H.—*Experiences with Multiple Fuel Firing*, Midwest Power Conference....Apr. 1948 36
Howard, Alan, J. I. Yellott, C. F. Kottcamp, J. R. Haskins, Jr., A. E. Hershey and J. H. Potter—*Gas Turbines*, A.S.M.E. Semi-Annual Meeting at Chicago..July 1947 28
Huffman, Dr. John R.—*Nuclear Engineering—Basic Design Background*, A.S.M.E. Annual Meeting....Dec. 1947 42
Humphreys, C. G. R., R. C. Corey, G. W. Bice, L. B. Schueler, W. T. Reid and A. R. Mumford—*Furnace Performance Factors*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 24
Humphreys, C. G. R.—*Early American Wooden Boilers*..Nov. 1947 38
Some Early Water-Tube Boilers....May 1948 38
Jessup, R. S., E. F. Fiock, F. W. Fuegg, A. G. Christie and R. V. Kleinschmidt—*Heating Value of Fuels*, A.S.M.E. Annual Meeting....Dec. 1947 38
Kane, L. J., and A. D. Singh—*New Process for Producing Char*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 31
Kleinschmidt, R. V., E. F. Fiock, R. S. Jessup, F. W. Fuegg and A. G. Christie—*Heating Value of Fuels*, A.S.M.E. Annual Meeting....Dec. 1947 38
Kottcamp, C. F., Alan Howard, J. I. Yellott, J. R. Haskins, Jr., A. E. Hershey and J. H. Potter—*Gas Turbines*, A.S.M.E. Semi-Annual Meeting at Chicago...July 1947 28
Krieg, E. H.—*Central Station Design*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 22
Kruse, J. R.—*Safety Valves for Stationary Power Boilers*..Mar. 1948 30
Lammers, H. B., C. A. Reed, P. F. White, C. F. Golding, H. L. Wagner, H. N. Hermann, W. H. Pugsley, C. E. Miller and J. F. Barkley—*Small Boiler Plant Problems*, Tenth Annual Joint Fuels Conference....Nov. 1947 30
Legget, R. F., R. L. Hearn and G. A. Gaffert—*Coal and Ash Handling*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 30
Lilienthal, David E.—*Atomic Energy and American Industry*....Nov. 1947 34
Atomic Energy and The Engineer, A.S.M.E. Annual Meeting....Dec. 1947 42
Lininger, B. A.—*Industrial Steam Plant Design*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 23
Martinelli, R. C. and D. B. Nelson—*Forced Circulation Boiling of Water*, A.S.M.E. Annual Meeting....Dec. 1947 43
Meissner, H. G.—*Burning Bagasse at Cuban Sugar Centrals*....Jan. 1948 26
Meldahl, A. H.—*Thermodynamics of Steam and Gas Turbines Compared*....Aug. 1947 43
Miller, C. E., C. A. Reed, P. F. White, C. F. Golding, H. L. Wagner, H. N. Hermann, W. H. Pugsley, H. B. Lammers and J. F. Barkley—*Small Boiler Plant Problems*, Tenth Annual Joint Fuels Conference....Nov. 1947 30
Mumford, A. R., L. B. Schueler, W. T. Reid, R. C. Corey, C. G. R. Humphreys and G. W. Bice—*Furnace Performance Factors*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 24
Mumford, A. R.—*Modern Boiler Design Increases Availability*....Feb. 1948 35
Münzinger, Dr. F. O. A.—*Some Notes on Boiler Practice in Germany*....Aug. 1947 41
Influences on Slag Behavior....Mar. 1948 32
Nelson, D. B., and R. C. Martinelli—*Forced Circulation Boiling of Water*, A.S.M.E. Annual Meeting....Dec. 1947 43
Neuberger, Hans—*Significance of Condensation Nuclei in Atmospheric Pollution*, Tenth Annual Joint Fuels Conference....Nov. 1947 32

PAGE

Nicholson, J. R., I. M. Stewart and H. P. Reinbach—*Burning Brown Coal on Stokers*....Nov. 1947 47
Nier, A. O., and B. R. Prentice—*Atomic Power*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 31
Oliver, A. S.—*Five Years Performance of Minnesota Paper Mill Steam Generating Unit*....Aug. 1947 28
Orning, A. A.—*Mechanism of Combustion of Pulverized Coal*....Sept. 1947 41
Owens, F. R.—*Silica Deposits in Steam Turbines from Softening of Makeup Through Natural Zeolite*....July 1947 37
Parker, Leo T.—*Court Decisions Affecting Power Plants*..Apr. 1948 47
Patterson, W. S.—*Factors in Selection of Steam Generating Units*....Mar. 1948 35
Pinkney, E. T., and R. S. Young—*Significance of Temperature in Titration of Iodine with Winkler Test for Dissolved Oxygen*....Oct. 1947 35
Pollock, W. A.—Fuels Performance at Port Washington Station....June 1948 41
Potter, James H., Alan Howard, J. I. Yellott, C. F. Kottcamp, J. R. Haskins, Jr., and A. E. Hershey—*Gas Turbines*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 28
Powell, E. M.—Lessons from the Tests and Present Status of the Art, Part II....June 1948 39
Prentice, B. R., and A. O. Nier—*Atomic Power*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 31
Pugsley, W. H.—*Instruments and Combustion Control for Small Plants*....Jan. 1948 41
Putz, T. J.—*Gas Turbine Test*, Midwest Power Conference....Apr. 1948 40
Reed, C. A., P. F. White, C. F. Golding, H. L. Wagner, H. N. Hermann, W. H. Pugsley, C. E. Miller, H. B. Lammers and J. F. Barkley—*Small Boiler Plant Problems*—Tenth Annual Joint Fuels Conference....Nov. 1947 30
Reed, Robert L.—*Corrosion: Its Effect in Boiler Systems, Part I*....May 1948 28
Part II....June 1948 43
Reed, R. S.—*Two Years Performance of the Chesterfield Power Station*....Apr. 1948 43
Reid, W. T., L. B. Schueler, R. C. Corey, A. R. Mumford, C. G. R. Humphreys and G. W. Bice—*Furnace Performance Factors*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 24
Reinbach, H. P., I. M. Stewart and J. R. Nicholson—*Burning Brown Coal on Stokers*....Nov. 1947 47
Rose, Dr. H. J.—*Steam Generation and Gas Turbine Developments in Switzerland*....Sept. 1947 35
Ryan, William F.—*Construction Cost Trends and Implications*....July 1947 33
Sachs, G.—*Expanded Tube Joints*, A.S.M.E. Annual Meeting....Dec. 1947 43
Schroeder, Dr. W. C., and H. Fies—*Underground Coal Gasification*, Tenth Annual Joint Fuels Conference...Nov. 1947 33
Schroeder, Dr. W. C.—*Synthetic Liquid Fuels*, A.S.M.E. Annual Meeting....Dec. 1947 41
Schueler, L. B., W. T. Reid, R. C. Corey, A. R. Mumford, C. G. R. Humphreys and G. W. Bice—*Furnace Performance Factors*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 24
Senior, F. C.—*Steam for Chile's New Steel Plant*....Apr. 1948 32
Singh, A. D., and L. J. Kane—*New Process for Producing Char*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 31
Smith, G. V., and H. S. Blumberg—*Boiler Drum Steel After Forty Years' Service*, A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 27
Sporn, Philip—*The New Sporn Station*, A.S.M.E. Annual Meeting....Dec. 1947 37
Steinberg, M. J., and W. F. Davidson—*Combined Steam and Electric Supply in New York*....Sept. 1947 30
Steinhoff, H. E.—*Illinois Power Company's New Havana Power Station*....Dec. 1947 32
Stewart, I. M., J. R. Nicholson and H. P. Reinbach—*Burning Brown Coal on Stokers*....Nov. 1947 47
Straub, F. G.—*Iron in Feedwater*, Midwest Power Conference....Apr. 1948 39
Szwander, W.—*Generating Station Auxiliaries*....Oct. 1947 41
Ulmer, Dr. R. C.—*Boiler Water Treatment*, Midwest Power Conference....Apr. 1948 38
Van Brunt, John—*An Appraisal of the Fuel Situation*, Midwest Power Conference....Apr. 1948 36
Wagner, H. L., C. A. Reed, P. F. White, C. F. Golding, H. N. Hermann, W. H. Pugsley, C. E. Miller, H. B. Lammers and J. F. Barkley—*Small Boiler Plant Problems*, Tenth Annual Joint Fuels Conference....Nov. 1947 30
White, P. F., C. A. Reed, C. F. Golding, H. L. Wagner, H. N. Hermann, W. H. Pugsley, C. E. Miller, H. B. Lammers and J. F. Barkley—*Small Boiler Plant Problems*, Tenth Annual Joint Fuels Conference....Nov. 1947 30
Williams, R. S., J. C. Falkner and R. H. Hare—*Quick Starting of High-Pressure Steam Turbine Units*....Aug. 1947 31
Yellott, J. I., Alan Howard, C. F. Kottcamp, J. R. Haskins, Jr., A. E. Hershey and J. H. Potter—*Gas Turbines*, A.S.M.E. Semi-Annual Meeting at Chicago...July 1947 28
Young, R. S. and E. T. Pinkney—*Significance of Temperature in Titration of Iodine with Winkler Test for Dissolved Oxygen*....Oct. 1947 35

PAGE

REVIEW OF NEW BOOKS—

Air Conditioning. By Herbert and Harold Herkimer . . . Dec. 1947 53
Air Conditioning and Elements of Refrigeration. By Samuel P. Brown . . . Oct. 1947 51
A.S.T.M. Specifications for Steel Pipe . . . June 1948 55
Boiler Fireman's Handbook. By Joseph R. Darnell . . . May 1948 53
Centrifugal and Axial Flow Pumps. By A. J. Stepanoff . May 1948 53
Coal and Coke Standards. Published by the American Society for Testing Materials . . . Dec. 1947 53
Combustion Engineering—First Edition. Edited by Otto de Lorenzi . . . Feb. 1948 55
Compressed Air Handbook—First Edition. Compiled by Compressed Air and Gas Institute . . . Oct. 1947 50
Elementary Physical Metallurgy. By Edward G. Mahin . . . May 1948 53
Engine Room Questions and Answers—First Edition. By Alex Higgins . . . May 1948 53
Fan Engineering. Edited by Richard D. Madison . . . June 1948 55
Instrument and Control Manual for Operating Engineers. By Eugene W. F. Feller . . . Feb. 1948 55
Jet Propulsion Progress. By Leslie E. Neville and N. F. Silsbee . . . May 1948 53
Locations of Electric Utility Stations. Published by Federal Power Commission . . . June 1948 55
Pressure Vessels for Industry—First Edition. By Harry M. Spring, Jr. . . . Oct. 1947 50
Results of Publicly Owned Electric System—Ninth Edition. Published by Burns & McDonnell Engineering Co. . . . May 1948 53
Steam, Air and Gas Power. By W. H. Severns and H. E. Degler . . . June 1948 55
Steam and Gas Engineering. By Butterfield, Jennings and Luce . . . Dec. 1947 52
Supercharging the Internal-Combustion Engine. By E. T. Vincent . . . May 1948 53
Synthetic Petroleum from the Synthine Process. By B. H. Weil and John C. Lane . . . May 1948 53
Textbook of Heat, A.—First Edition. By G. R. Noakes. Dec. 1947 52

CLASSIFIED INDEX—

Acid Cleaning

Corrosion as Related to Acid Cleaning . . . Aug. 1947 35

Ash

Behavior of Ash in Pulverized-Coal-Fired Furnaces. By P. Cohen and R. C. Corey . . . Jan. 1948 33

Auxiliaries

Generating Station Auxiliaries. By W. Szwander . . . Oct. 1947 41

Bagasse

Burning Bagasse at Cuban Sugar Centrals. By H. G. Meissner . . . Jan. 1948 26

Bark Burning

Bark Burning Methods. By J. H. Freiday . . . Oct. 1947 45

Boilers

Boiler Drum Steel After Forty Years' Service, *A.S.M.E. Semi-Annual Meeting at Chicago.* By H. S. Blumberg and G. V. Smith . . . July 1947 27
Corrosion as Related to Acid Cleaning . . . Aug. 1947 35
Early American Wooden Boilers. By C. G. R. Humphreys . . . Nov. 1947 38
Expanded Tube Joints, *A.S.M.E. Annual Meeting.* By G. Sachs . . . Dec. 1947 43
Factors in Selection of Steam Generating Units. By W. S. Patterson . . . Mar. 1948 35
Feedwater and Blowoff Calculations. By V. J. Calise . . . June 1948 51
Furnaces for By-Product Fuels, *A.S.M.E. Annual Meeting.* By Otto de Lorenzi . . . Dec. 1947 40
Modern Boiler Design Increases Availability. By A. R. Mumford . . . Feb. 1948 35
Safety Valves for Stationary Power Boilers. By J. R. Kruse . . . Mar. 1948 30
Some Early Water-Tube Boilers. By C. G. R. Humphreys . . . May 1948 38
Some Notes on Boiler Practice in Germany. By Dr. F. O. A. Münzinger . . . Aug. 1947 41

PAGE

Sulphate-Type Deposits on Boiler Tubes, *A.S.M.E. Semi-Annual Meeting at Chicago.* By J. F. Barkley, L. R. Burdick and A. A. Berk . . . July 1947 26
Work of Fuel Research Station in Study of Boiler Deposits . . . Aug. 1947 37

Coals

Mechanism of Combustion of Pulverized Coal. By A. A. Orning . . . Sept. 1947 41

Coal and Ash Handling Systems

Coal and Ash Handling, *A.S.M.E. Semi-Annual Meeting at Chicago.* By R. L. Hearn, R. F. Legget and G. A. Gaffert . . . July 1947 30

Combustion

Experimental Combustion of Pulverized Coal at Atmospheric and Elevated Pressures, *A.S.M.E. Annual Meeting.* By Herbert R. Hazard and Fred D. Buckley . . . Dec. 1947 41
Mechanism of Combustion of Pulverized Coal. By A. A. Orning . . . Sept. 1947 41

Combustion Control

Instruments and Combustion Control for Small Plants. By W. H. Pugsley . . . Jan. 1948 41

Corrosion

Corrosion as Related to Acid Cleaning . . . Aug. 1947 35
Corrosion: Its Effect in Boiler Systems. By Robert L. Reed—Part I . . . May 1948 28
Part II . . . June 1948 43

Design

Central Station Design, *A.S.M.E. Semi-Annual Meeting at Chicago.* By E. H. Krieg . . . July 1947 22
Industrial Steam Plant Design, *A.S.M.E. Semi-Annual Meeting at Chicago.* By B. A. Lininger . . . July 1947 23

Fans

Selection of Mechanical Draft Fans, The. By A. P. Darlington . . . May 1948 35

Flash Drying

Flash Drying of Materials by a New Method, *A.S.M.E. Annual Meeting.* By C. W. Gordon . . . Dec 1947 43

Fuels

Burning Brown Coal on Stokers. By I. M. Stewart, J. R. Nicholson and H. P. Reinbach . . . Nov. 1947 47
Coal Facts . . . June 1948 53
Experiences with Multiple Fuel Firing, *Midwest Power Conference.* By F. H. Hollis . . . Apr. 1948 36
Furnaces for By-Product Fuels, *A.S.M.E. Annual Meeting.* By Otto de Lorenzi . . . Dec. 1947 40
Heating Value of Fuels, *A.S.M.E. Annual Meeting.* By E. F. Fiock, R. S. Jessup, F. W. Fuegg, A. G. Christie and R. V. Kleinschmidt . . . Dec. 1947 38
Power Conference Reports on the World Fuel Situation . . . Oct. 1947 30
Small Boiler Plant Problems, *Tenth Annual Joint Fuels Conference.* By C. A. Reed, P. F. White, C. F. Golding, H. L. Wagner, H. N. Hermann, W. H. Pugsley, C. E. Miller, H. B. Lammers and J. F. Barkley . . . Nov. 1947 30
Synthetic Fuels Plants Recommended . . . Feb. 1948 49
Synthetic Liquid Fuels, *A.S.M.E. Annual Meeting.* By Dr. W. C. Schroeder . . . Dec. 1947 41
Underground Coal Gasification, *Tenth Annual Joint Fuels Conference.* By W. C. Schroeder and H. Fies . . . Nov. 1947 33
World-Wide Oil Demand and Supply. By R. M. Bartlett . . . May 1948 40

Furnaces

Furnace Performance Factors, *A.S.M.E. Semi-Annual Meeting at Chicago.* By L. B. Schueler, W. T. Reid, R. C. Corey, A. R. Mumford, C. G. R. Humphreys and G. W. Bice . . . July 1947 24
Furnaces for By-Product Fuels, *A.S.M.E. Annual Meeting.* By Otto de Lorenzi . . . Dec. 1947 40
Influences on Slag Behavior. By Dr. F. O. A. Münzinger . . . Mar. 1948 32

PAGE

Gas Turbines

An Appraisal of the Gas Turbine for Power Plants. By A. G. Christie....Nov. 1947 41
Gas Turbine History. By T. A. Crowe....Mar. 1948 46
Gas Turbines, *A.S.M.E. Semi-Annual Meeting at Chicago.* By Alan Howard, J. I. Yellott, C. F. Kottcamp, J. R. Haskins, Jr., A. E. Hershey and J. H. Potter...July 1947 28
Gas Turbine Test, *Midwest Power Conference.* By T. J. Putz....Apr. 1948 40
Steam Generation and Gas Turbine Developments in Switzerland. By Dr. H. J. Rose....Sept. 1947 35
Thermodynamics of Steam and Gas Turbines Compared. By A. H. Meldahl....Aug. 1947 43

Installations

Calumet Station, Commonwealth Edison Company
Large Generating Unit Goes Into Service at Chicago...Oct. 1947 38
Chesterfield Power Station, Virginia Electric and Power Company
Two Years Performance of the Chesterfield Power Station. By R. S. Reed....Apr. 1948 43
Compania de Acero del Pacifico
Steam for Chile's New Steel Plant. By F. C. Senior..Apr. 1948 32
Havana Power Station, Illinois Power Company
Illinois Power Company's New Havana Power Station. By H. E. Steinhoff....Dec. 1947 32
Keystone Steel & Wire Company
Keystone Steel & Wire Co. Adds to Boiler Capacity. By Walter Gaumer and M. O. Funk....Feb. 1948 32
Minnesota & Ontario Paper Company, International Falls, Minn.
Five Years Performance of Minnesota Paper Mill Steam Generating Unit. By A. S. Oliver....Aug. 1947 28
Philip Sporn Station, American Gas & Electric Company
The New Sporn Station, A.S.M.E. Annual Meeting. By Philip Sporn....Dec. 1947 37
Port Washington Station, Wisconsin Electric Power Company
Fuels Performance at Port Washington....June 1948 41
Victor Chemical Works, Chicago Heights, Ill.
Test of a Continuous-Discharge, Spreader-Stoker-Fired Unit. By M. O. Funk....Sept. 1947 37

Nuclear Energy

Atomic Energy and American Industry. By David E. Lilienthal....Nov. 1947 34
Atomic Energy and The Engineer, *A.S.M.E. Annual Meeting.* By David E. Lilienthal....Dec. 1947 42
Nuclear Engineering—Basic Design Background, *A.S.M.E. Annual Meeting.* By Dr. John R. Huffman....Dec. 1947 42

Piping

Notes on Radiology of Welded Pipe Joints....Jan. 1948 44

Performance

Five Years Performance of Minnesota Paper Mill Steam Generating Unit. By A. S. Oliver....Aug. 1947 28
Two Years Performance of the Chesterfield Power Station. By R. S. Reed....Apr. 1948 43

Power Statistics

Future Electric Power Needs of the U. S., *Midwest Power Conference.* By F. R. Benedict....Apr. 1948 36
Japanese Electric Power System, *Midwest Power Conference.* By E. J. Burger....Apr. 1948 39

Pulverized Coal

Pioneer Work at Milwaukee. By F. L. Dornbrook....June 1948 32
Lessons from the Tests and Present Status of the Art,
Part I. By B. J. Cross....June 1948 36
Part II. By E. M. Powell....June 1948 39

Reheat

A Sub-Saturation Reheat Cycle. By W. E. Caldwell..Feb. 1948 45
Is Reheat Coming Back?....Sept. 1947 33

Smoke Abatement

Small Boiler Plant Problems, *Tenth Annual Joint Fuels Conference.* By C. A. Reed, P. F. White, C. F. Golding, H. L. Wagner, H. N. Hermann, W. H. Pugsley, C. E. Miller, H. B. Lammers and J. F. Barkley....Nov. 1947 30
Significance of Condensation Nuclei in Atmospheric Pollution, *Tenth Annual Joint Fuels Conference.* By Hans Neuberger....Nov. 1947 32
Stability of the Atmosphere and Its Influence on Air Pollution, *Tenth Annual Joint Fuels Conference.* By Henry F. Hebley....Nov. 1947 33

Steam Cycles

A Sub-Saturation Reheat Cycle. By W. E. Caldwell..Feb. 1948 45
Is Reheat Coming Back?....Sept. 1947 37

Steam Turbines

Industrial Turbine Maintenance. By G. W. Anderson..May 1948 43
Quick Starting of High-Pressure Steam Turbine Units. By J. C. Falkner, R. S. Williams and R. H. Hare....Aug. 1947 31
Removal of Silica Deposits from Steam Turbines by Caustic Soda. By I. B. Dick....Dec. 1947 44
Silica Deposits in Steam Turbines from Softening of Makeup Through Natural Zeolite. By F. R. Owens..July 1947 37
Thermodynamics of Steam and Gas Turbines Compared. By A. H. Meldahl....Aug. 1947 43

Stokers

Burning Brown Coal on Stokers. By I. M. Stewart, J. R. Nicholson and H. P. Reinbach....Nov. 1947 47
Power Conference Reports on the World Fuel Situation..Oct. 1947 30
Small Boiler Plant Problems, *Tenth Annual Joint Fuels Conference.* By C. A. Reed, P. F. White, C. F. Golding, H. L. Wagner, H. N. Hermann, W. H. Pugsley, C. E. Miller, H. B. Lammers and J. F. Barkley....Nov. 1947 30
Test of a Continuous-Discharge, Spreader-Stoker-Fired Unit. By M. O. Funk....Sept. 1947 37
Burning Bagasse at Cuban Sugar Centrals. By H. G. Meissner....Jan. 1948 26

Synthetic Fuels

Synthetic Fuels Plants Recommended....Feb. 1948 46
Synthetic Liquid Fuels, *A.S.M.E. Annual Meeting.* By Dr. W. C. Schroeder....Dec. 1947 41

Water Conditioning

Boiler Water Treatment, *Midwest Power Conference.* By Dr. R. C. Ulmer....Apr. 1948 38
Hot-Process Conditioned Water for High-Pressure Boilers. By A. C. Dresher....Jan. 1948 31
Iron in Feedwater, *Midwest Power Conference.* By F. G. Straub....Apr. 1948 39
Significance of Temperature in Titration of Iodine with Winkler Test for Dissolved Oxygen. By E. T. Pinkney and R. S. Young....Oct. 1947 35
Silica Deposits in Steam Turbines from Softening of Makeup Through Natural Zeolite. By F. R. Owens..July 1947 37
Sulphate-Type Deposits on Boiler Tubes, *A.S.M.E. Semi-Annual Meeting at Chicago.* By J. F. Barkley, L. R. Burdick and A. A. Berk....July 1947 26
High Alkalinity and Organic Materials for Sludge Removal, *Midwest Power Conference.* By Selden K. Adkins....Apr. 1948 38

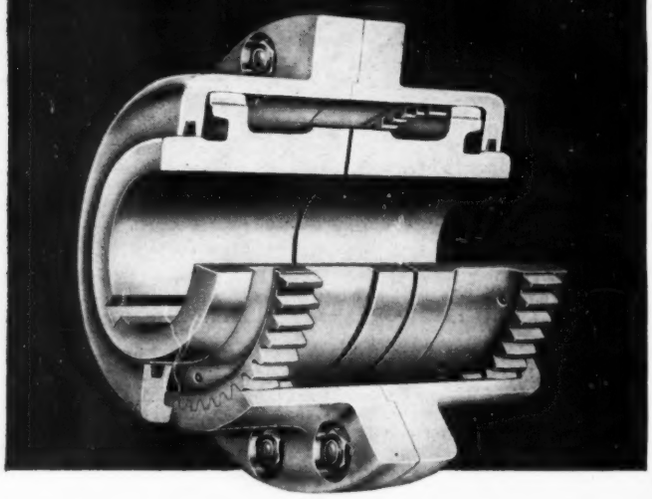
X-Ray

Notes on Radiology of Welded Pipe Joints....Jan. 1948 44
X-Ray Protection Being Studied....July 1947 41

Miscellaneous

A.S.M.E. Meets at Atlantic City....Dec. 1947 37
A.S.M.E. Semi-Annual Meeting at Chicago....July 1947 22
Combined Steam and Electric Supply in New York. By W. F. Davidson and M. J. Steinberg....Sept. 1947 30
Construction Cost Trends and Implications. By Wm. F. Ryan....July 1947 33
Court Decisions Affecting Power Plants. By Leo T. Parker....Apr. 1948 47
Energy Sources and Output by Electric Utilities....Mar. 1948 43
Engineers Discuss How to Keep Power Boilers in Uninterrupted Service....Feb. 1948 43
Federal Power Commission Urges Further Interconnection....Dec. 1947 49
Industrial Steam Plant Design, *A.S.M.E. Semi-Annual Meeting at Chicago.* By B. A. Lininger....July 1947 23
New Process for Producing Char, *A.S.M.E. Semi-Annual Meeting at Chicago.* By A. D. Singh and L. J. Kane....July 1947 31
Power Plant Operator Training, *Midwest Power Conference.* By J. P. Flynn, Garrett Burgess, Kenneth Hodges, Stephen C. Casteel and Julius Barbour....Apr. 1948 40
Steam-Electric Power in Spain. By Saturnio Alverez..May 1948 33
Trek of Industry Westward, The, *Midwest Power Conference.* By John M. Drabelle....Apr. 1948 36

POOLE



A COPY OF CATALOG GIVING FULL DESCRIPTION AND ENGINEERING DATA SENT UPON REQUEST.

FLEXIBLE COUPLINGS

POOLE FOUNDRY & MACHINE COMPANY WOODBERRY, BALTIMORE, MD.

Hi-Pressure Gage Glasses

Round, Tubular and Flat Type

Fig. 12

RUBBER GAGE GLASS GASKETS

Series 750 . . . All Sizes

Fig. 21 Fig. 22

Other Ernst Specialties

are given in Catalog No. 48 P

GAGE GLASS ILLUMINATORS
NEW PLASTIC GUARDS
SIGHT FLOW INDICATORS
SPLIT-GLAND WATER GAGE
STEEL GAGE VALVES
FLAT GLASS INSERTS
ALL IRON GAGES
HIGH & LOW ALARM COLUMNS
MICA SHIELDS AND GASKETS
AND OTHER HELPFUL TIPS ON
BOILER ROOM SAFETY

Inclined for Better Visibility

Standard Type—Offset Adjustable Inclined Gage Fittings

Fig. 4-F

Fig. 13

Leakless Super Try Cocks, Bronze and Forged Steel Construction

Send for Catalog 48P

Ernst WATER COLUMN & GAGE CO.

LIVINGSTON, N. J. LIVINGSTON 6-1400

NEED A HIGH SPEED PUMP?

Install an **IMO**

The IMO Pump can be operated at motor and turbine speeds. It is ideal for direct connection and integral mounting. Excepting for the flow and vaporization characteristics of the fluid being pumped, there's practically no limit to the speed at which an IMO Pump can be operated.

IMO Pumps can be furnished for practically any capacity and pressure required for oil, hydraulic-control fluids and other liquids.

Send for Bulletin I-147V.

IMO means I MOVE OIL

IMO PUMP DIVISION of the
DE LAVAL STEAM TURBINE CO.
TRENTON 2, NEW JERSEY

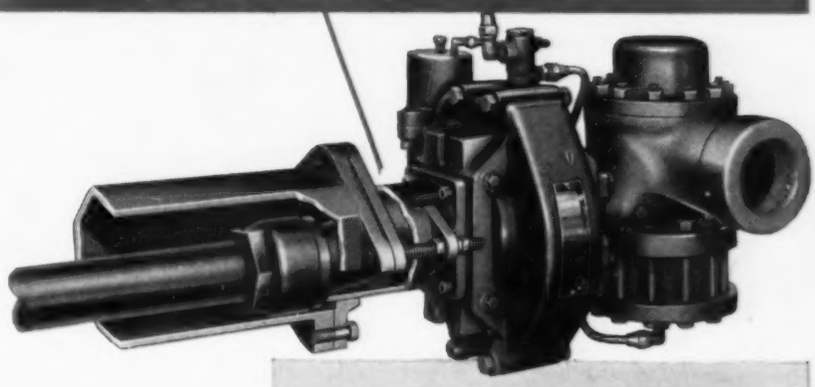
Advertisers in This Issue

Air Preheater Corporation, The	23
American Blower Corporation	26
Armstrong Cork Company	21
Armstrong Machine Works	49
Theo. Audel & Company, Publishers	41
Bailey Meter Company	20
Bayer Company, The	57
Beaumont Birch Company	53
W. H. & L. D. Betz	Fourth Cover
Bird-Archer Company, The	5
Buell Engineering Company, Inc.	30
Buffalo Forge Company	13
Cambridge Instrument Company, Inc.	52
Combustion Engineering Company, Inc.	Second Cover, 24 and 25
De Laval Steam Turbine Company	22 and 64
Diamond Power Specialty Corporation	Third Cover
Edward Valves, Inc.	15
Ernst Water Column & Gage Company	64
Foster Engineering Company	6
General Electric Company	16 and 17
Globe Steel Tubes Company	27
Hagan Corporation	10 and 11
Hall Laboratories	10 and 11
Ingersoll-Rand Company	50
Johns-Manville	19
Northern Equipment Company	2
Ohio Coal Association	58
Peabody Engineering Corporation	14
Poole Foundry & Machine Company	64
Wm. Powell Company, The	56
Prat-Daniel Corporation	3
Refractory & Insulation Corporation	12
Reliance Gauge Column Company, The	18
Sauerman Bros., Inc.	55
Snyder & Swanson, Inc.	42
Stock Engineering Company	54
Swartwout Company, The	29
Terry Steam Turbine Company, The	8
Thermix Corporation, The	7
Vulcan Soot Blower Corporation	28
Yarnall-Waring Company	4 and 9

JUST OPEN ONE VALVE.

the Entire Boiler is CLEANED CORRECTLY

BY DIAMOND AUTOMATIC "AIR PUFF" SOOT BLOWERS



Correct cleaning *every time* is assured when you have Diamond Automatic "Air Puff" Soot Blowers.

Just a "twist of the wrist" to open one valve and the Master Controller does the rest. Each soot blower is operated correctly in its predetermined sequence. The operation continues until the entire blowing cycle is finished. Then the Master Controller shuts off automatically.

Diamond "Air Puff" Soot Blower elements are permanently installed in the setting. Compressed air is discharged from multiple nozzles in a series of short puffs with pauses between. During each puff, the element is automatically rotated through a small arc; there are sufficient puffs to sweep the surfaces to be cleaned.

The greater density of compressed air as compared to steam provides better cleaning. By discharging the air in puffs with pauses between, the cleaning cycle is spread over a longer period that permits use of a much smaller compressor and receiver. The automatic operation eliminates the human element—boilers *can't* be cleaned incorrectly.

Ask for Catalog No. 1014 for complete information about Diamond Soot Blowers.

DIAMOND POWER SPECIALTY CORP.

DETROIT 31, MICHIGAN

Diamond Specialty Limited • Windsor, Ontario

OTHER ADVANTAGES

SAVES LABOR—No attendant needed to drain piping, warm up and operate each individual blowing unit.

SAVES FUEL—Uses only ½ to ⅔ of energy from coal pile needed for steam blowing.

NO FEED WATER MAKEUP

STACK DISCHARGE NUISANCE MINIMIZED—Intermittent operation expels soot in small quantities.

REDUCED MAINTENANCE

PIPING INSULATION ELIMINATED

3538

Let's Talk About *Your* Boiler Plant

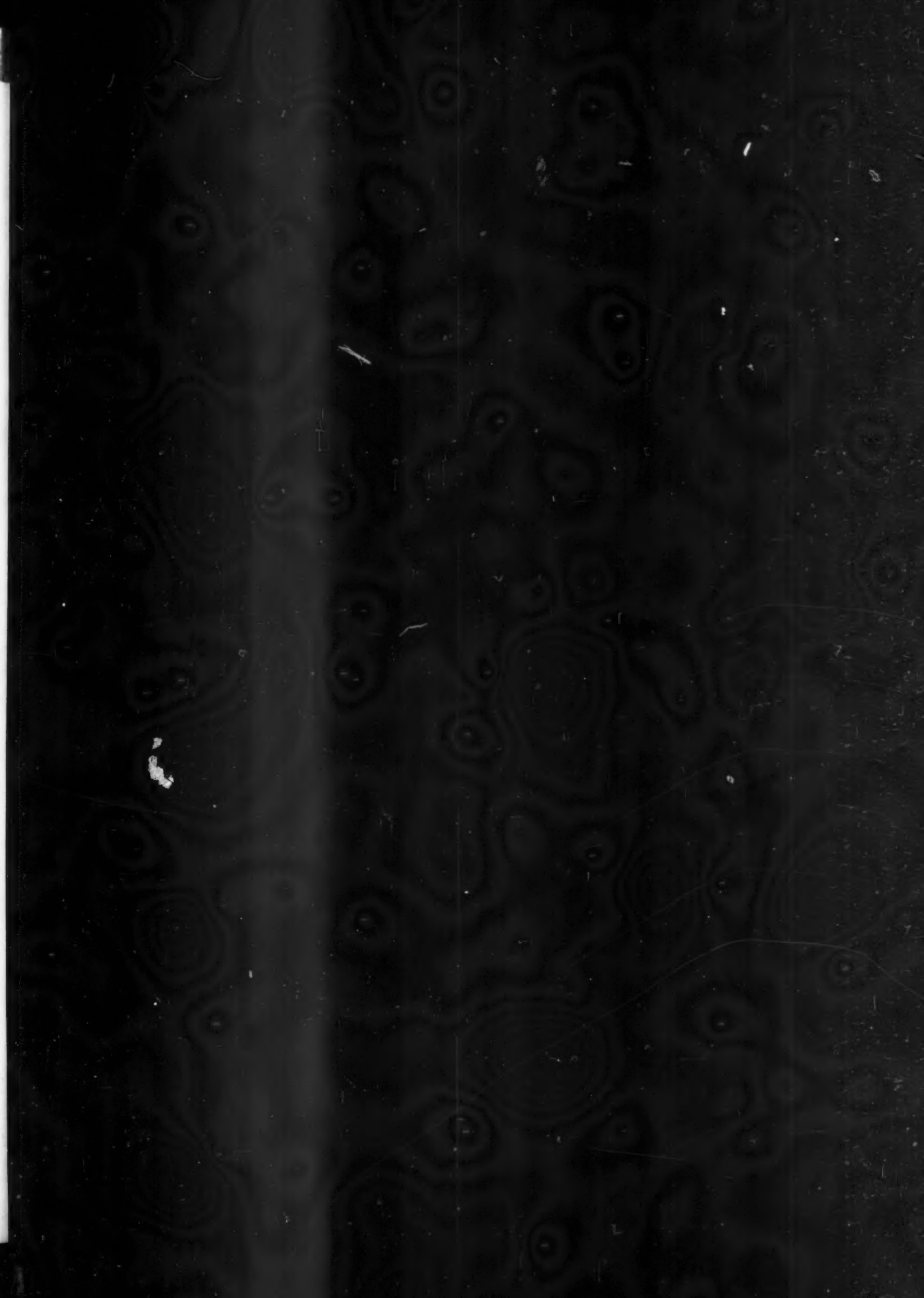
In particular, let's talk about water conditioning in your boiler plant.

First, we should recognize that complete and efficient water conditioning starts with the raw water and continues through the plant, taking in many problems. "Trouble-spots" may occur at many points throughout the system—from the raw water intake to the boiler blowdown discharge.

Secondly, *correct* water conditioning is a matter of careful and scientific control. For proper results you should be sure to choose a water conditioning service offering the very best in up to date engineering practice.

W. H. & L. D. BETZ is an organization of engineers and chemists specializing in the solution of all industrial water problems. Years of experience have made Betz water conditioning service scientifically correct . . . complete . . . economical.

Our nationwide staff of engineers will welcome the opportunity of discussing with you this important subject of water conditioning . . .
W. H. & L. D. BETZ, Gillingham and Worth Streets, Philadelphia 24, Pa.
In Canada: Betz Laboratories Limited, Montreal 1.

BETZ

BOILER WATER CONDITIONING • COOLING WATER CONDITIONING • INDUSTRIAL WASTE TREATMENT